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The Johns Hopkins University

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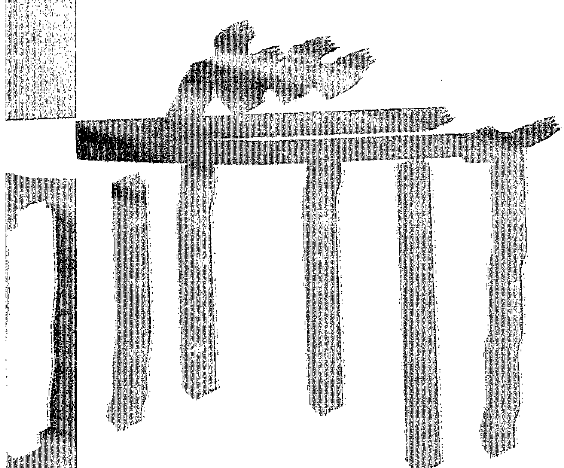
International Symposium on Nondestructive Characterization of Materials™

24-28 June 2002, Berlin, Germany



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LASER ULTRASONICS
X-RAY SCATTERING
ULTRASONIC WAVES
X-RAY SCATTERING
MICROWAVES
ULTRASONICS
EDDY CURRENTS
RADIOGRAPHY AND TOMOGRAPHY
MAGNETIC METHODS
THERMAL CHARACTERIZATION
OPTICAL CHARACTERIZATION
PLENARY
AEROSPACE MATERIALS
CIVIL STRUCTURES
MATERIALS CHARACTERIZATION
PROCESS CONTROL
COMPOSITES
SURFACES AND BONDS

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NONDESTRUCTIVE CHARACTERIZATION OF MATERIALS™
JUNE 24-28, 2002, BERLIN, GERMANY

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11TH INTERNATIONAL SYMPOSIUM ON
NONDESTRUCTIVE CHARACTERIZATION OF MATERIALS™
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CONTENTS

11TH INTERNATIONAL SYMPOSIUM ON
NONDESTRUCTIVE CHARACTERIZATION OF MATERIALS™
JUNE 24-28, 2002, BERLIN, GERMANY

TIMETABLE AND CHAIRS

11TH INTERNATIONAL SYMPOSIUM
NONDESTRUCTIVE CHARACTERIZATION OF MATERIALS™
JUNE 24-28, 2002 IN BERLIN

SESSION CHAIRS

	Sessions A		chaired by
Monday, June 24			
11:00 - 12:00	**opening session**		M.P. Hentschel
13:30 - 15:30	**A01**	laser ultrasonics	R.J. Dewhurst • G. Thomas
16:00 - 17:40	**A02**	ultrasonic waves I	D. Cerniglia • M.J. Quarry
Tuesday, June 25			
08:00 - 10:00	**A03**	ultrasonic waves II	V. Bucur • K. Kawashima
10:30 - 12:10	**A04**	ultrasonics I	S. Biwa • P.D. Panetta
13:40 - 15:20	**A05**	ultrasonics II	P.P. Del Santo • K.G. Schmitt-Thomas
15:50 - 17:50	**A06**	eddy currents	M. Zergoug • V. Zilberstein
Wednesday, June 26			
08:00 - 10:00	**A07**	magnetic methods	C. Mandache • S. Pirfo
10:30 - 12:30	**A08**	optical characterization	J.B. Goodell • P.J. Kulowitch
Thursday, June 27			
08:30 - 09:50	**A09**	plenary	M.P. Hentschel
10:20 - 12:00	**A10**	aerospace materials	W.H. Green • K.G. Lipetzky
13:30 - 15:50	**A11**	materials characterization I	W. Morgner • E. Schneider
Friday, June 28			
08:00 - 10:00	**A12**	materials characterization II	G.A. Matzkanin • K.L. Murty
10:30 - 12:30	**A13**	materials characterization III	G. Busse • H. Ogi

	Sessions B		chaired by
Monday, June 24			
13:30 - 15:30	**B01**	X-ray scattering I	C. Landron • B.R. Müller
16:00 - 18:00	**B02**	X-ray scattering II	M. Katho • M. Kurita
Tuesday, June 25			
08:00 - 10:00	**B03**	microwaves I	G.W. Carriveau • R. Zoughi
10:30 - 12:10	**B04**	microwaves II	G.W. Carriveau • R. Zoughi
13:40 - 15:20	**B05**	microwaves III	S. Kharkovsky • T. Lasri
15:50 - 17:30	**B06**	radiography and tomography	V. Artemiev • W.H. Green
Wednesday, June 26			
08:00 - 10:00	**B07**	thermal characterization	I. Perez • S.M. Shepard
Thursday, June 27			
10:20 - 12:00	**B10**	civil structures	R.A. Livingston • H. Wiggenhauser
13:30 - 15:50	**B11**	process control	R.G. Maev • T. Saito
Friday, June 28			
08:00 - 10:00	**B12**	composites	V. Trappe • G.L. Workman
10:30 - 11:50	**B13**	surfaces and bonds	C. Byrne • O. Vertsanova

11TH INTERNATIONAL SYMPOSIUM ON
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JUNE 24-28, 2002, BERLIN, GERMANY

UPDATED PROGRAMME
(JUNE 11, 2002)

LASER ULTRASONICS A01

A01-1 13:30 **A Laser-Ultrasound/EMAT Imaging System for Near Surface Examination of Defects**
R. J. Dewhurst, S. Boonsang, P.R. Murray, Manchester (UK)

A01-2 13:50 **Ultrasonic Technology for Characterizing Laser Damage in Optics**
G. Thomas, L.P. Martin, D. Chambers, Livermore (USA)

A01-3 14:10 cancelled

A01-4 14:30 **Laser-Air Hybrid Ultrasonic Technique for the Inspection of Rail Steel**
S. Kenderian, B.B. Djordjevic, R.E. Green, Jr., Baltimore (USA)

A01-5 14:50 **Laser-Ultrasonics monitoring of LC Steel Absorption During Annealing**
S.E. Kruger, S. Bolognini, Boucherville (Canada)

A01-6 15:10 **Characterization of Steels with Ultra-Fine Grain by Ultrasonic Measurement Using Laser Ultrasonics**
H. Yamawaki, A. Ohomori, T. Saito, Ibaraki (Japan)

15:30 Coffee break

X-RAY SCATTERING I B01

B01-1 13:30 **X-Ray Diffraction and Refraction Topography of light Weight materials**
M.P. Hentschel, K.-W. Harbich, A. Lange, J. Schors, O. Wald, Berlin (Germany)

B01-2 14:10 **Synchrotron Radiation Refraction Topography**
B.R. Müller, A. Lange, M.P. Hentschel, Berlin (Germany)

B01-3 14:30 **X-Ray Refraction Topography of Impact Damage of CFRP Laminates**
O. Bullinger, G. Busse, Stuttgart (Germany); K.-W. Harbich, Berlin (Germany)

B01-4 14:50 **Precise Measurements of Fibre Direction, Type and Content in CFRP by X-Ray Rotation Topography**
J. Schors, A. Lange, M.P. Hentschel, Berlin (Germany)

B01-5 15:10 cancelled

15:30 Coffee break

ULTRASONIC WAVES I

A02

A02-1 16:00 **Negative Poisson's Ratios in Wood and Particle-Board with Ultrasonic Technique**
V. Bucur, S. Kazemi Najafi, Vandoeuvre les Nancy (France)

A02-2 16:20 **Characterization of Plastically Deformed Steel Utilizing EMAT Ultrasonic Velocity Measurements**
P.D. Panetta, A. Diaz, R. Pappas, B. Francini, K. Johnson, Richland (USA); G. Alers (USA)

A02-3 16:40 **A Mixed-Spectral Method for Exact Measurement of Phase Velocity of Multi-Mode Lamb Waves**
Z.Q. Liu, X. Liu, D. Ta, Shanghai (China)

A02-4 17:00 **Wood slowness surfaces in tridimensional representation**
V. Bucur, Vandoeuvre les Nancy (France); P. Lanceleur (France), B. Rogé, Ottawa (Canada)

A02-5 17:20 cancelled

17:40 End of session

X-RAY SCATTERING II

B02

B02-1 16:00 **Characterization of Microstress States in Polycrystalline Materials**
H. Behnken, Aachen (Germany)

B02-2 16:20 **Nondestructive Analysis of Liquid Oxides in Contactless Conditions by Synchrotron Radiation and Neutrons**
C. Landron, Orleans-Cedex (France)

B02-3 17:00 cancelled

B02-4 17:20 **X-Ray Stress Measurement of Materials Having Nonlinear $Sin^2\Psi$ Diagram**
M. Kurita, Nagaoka (Japan)

B02-5 17:40 **X-Ray Study on Plastic Strain Distribution in Soft Zone of A5052-H Weld Metal**
M. Katoh, K. Nishio, T. Yamaguchi, Kitakyushu (Japan)

18:00 End of session

ULTRASONIC WAVES II — A03

A03-1 8:00 **Analysis of Laser-Generated Lamb Waves with Wavelet Transform**
D. CERNIGLIA, B.B. DJORDJEVIC, BALTIMORE (USA)

A03-2 8:20 **Ultrasonic Quantitative NDE of Defect in Plate Structure Using Multi-Mode Lamb Waves**
Z.Q. LIU, SHANGHAI (CHINA)

A03-3 8:40 **Non-Contact Flaw Detection in Thin Plates Using Various Modes of Lamb´s Wave with Laser Ultrasonics**
M. MURASE, K. KAWASHIMA, NAGOYA (JAPAN)

A03-4 9:00 **Identification of Subsurface Void Size and the Depth in Ceramics with Frequency Spectra of Leaky Rayleigh Wave**
K. KAWASHIMA,. T. ITO, R. OMOTE, Y. HATTORI, NAGOYA (JAPAN)

A03-5 9:20 **Optimization of Lamb Wave Flaw Sensitivity Using Phased Array Excitation**
M.J. QUARRY, LIVERMORE (USA)

A03-6 9:40 **Excitation of Thin Plate Vibrations by Laser Pulses**
L.M. LYAMSHEV, M.L. LYAMSHEV, MOSCOW (RUSSIA)

10:00 Coffee break

MICROWAVES I — B03

B03-1 8:00 **Nondestructive Evaluation and Characterization of Complex Composite Structures**
G.W. CARRIVEAU, SAN DIEGO (USA); R. ZOUGHI, ROLLA (USA)

B03-2 8:40 **Inspection of Dielectric Materials with Microwaves**
S. PREDAK, T. RINGGER, S. AICHER, G. BUSSE, STUTTGART (GERMANY)

B03-3 9:00 **Characterization of Layered Dielectric Composites by Radar Techniques**
J.M. LIU, WEST BETHESDA (USA)

B03-4 9:20 **Detection of Hidden Corrosion under Paint**
J. OTTO, M. HALD, AALEN (GERMANY)

B03-5 9:40 **Near-Field Inspection of Thermal Barrier Coating for Thickness, Disbond, Delamination, Corrosion and Porosity**
R. ZOUGHI, K. MUNOZ, ROLLA (USA)

10:00 Coffee break

ULTRASONICS I

A04

A04-1 10:30 **Ultrasonic Attenuation and Backscattering in Duplex Alloys for Materials Characterization**
P.D. Panetta, Richland (USA); R.B. Thompson (USA)

A04-2 10:50 **Ultrasound Laminography – A New Method to Detect Deterioration of Materials an Creep Load**
K.G. Schmitt-Thomas, E. Tolksdorf (Speaker), E. Kellerer, München (Germany)

A04-3 11:10 cancelled

A04-4 11:30 **Experimental and Theoretical Evaluation of Ultrasonic Attenuation in Carbon/Epoxy Composites**
S. Biwa, Y. Watanabe, N. Ohno, Nagoya (Japan)

A04-5 11:50 **Application of Signal Processing in Ultrasonic Characterization of Multi-Layered Composite Materials**
R. Kazys, L. Mazeika, V. Paulauskas, R. Raisutis, Kaunas (Lithuania)

12:10 Lunch break

MICROWAVES II

B04

B04-1 10:30 **Microwave Nondestructive Evaluation and Characterization of Tank Inner-Liners**
G.W. Carriveau, San Diego (USA); R. Zoughi, D. Hughes, Rolla (USA); N. Qaddoumi, Sharja (Unitet Arab Emirates)

B04-2 10:50 **Mapping of Porosity Clusters in Marine Composi-tes Using Millimeter Wave**
J.M. Liu, West Bethesda (USA)

B04-3 11:10 **Near-Field Microwave and Embedded Modulated Scattering Techniques for Dielectric Characterization of Material**
D. Hughes, R. Zoughi, Rolla (USA)

B04-4 11:30 **Inversion Procedures for Microwave NDE Applications**
M. Pastorino A. Randazzo, Genova (Italy); S. Caorsi, Pavia (Italy); A. Massa, Trento (Italy)

B04-5 11:50 **Characterization of Surface Cracks in Metals by Microwave Techniques**
T. Lasri, D. Glay, Villeneuve d´Ascq Cedex (France)

12:10 Lunch break

ULTRASONICS II A05

A05-1 13:40 **Air-coupled Ultrasound Inspection for Material Characterization in Linear, Non-Linear, and Slanted Transmission Mode**
S. Predak, R. Stößel, G. Busse, Stuttgart (Germany); I. Solodov, Moscow (Russia)

A05-2 14:00 **Ultrasonic Testing of Bonds on Aluminium Extruded Profiles**
K.K. Borum, Roskilde (Denmark)

A05-3 14:20 **Real-time Ultrasonic Imaging Using CCD Camera Techniques**
W.R. Davis, Patuxent River (USA); B. Lasser, Silver Spring (USA)
presented by P.J. Kulowitch, Patuxent River (USA)

A05-4 14:40 **LISA Simulations of Time Reverse Acoustics and Ultrasonics Experiments**
P.P. Delsanto, M. Scalerandi, Torino (Italy); R. Guyer, Amherst (USA); P. Johnson, J. Tencate, Los Alamos (USA)

A05-5 15:00 **Temperature Effect of Mechnical Damping and Anisotropic Elastic Properties of Zr-2.5Nb Pressure Tube Using Resonant Ultrasonic Spectroscopy**
Y.-M. Cheong, H.-K. Jung, Y.-S. Kim, Taejon (Korea)

15:20 Coffee break

MICROWAVES III B05

B05-1 13:40 **Combined Bi-Static Near-Field Microwave and Modulated Scattering Techniques for Detection of Embedded Targets**
D. Hughes, J. Lai, C. Behrens, R. Zoughi, Rolla (USA)

B05-2 14:00 **Microwave Reflection and Dielectric Properties of Mortar Exposed to Periodic Chloride Solution with 1% Salinity and Compression Force**
R. Zoughi, T. Case, S. Peer, E. Gallaher, Rolla (USA); K. Kurtis, Atlanta (USA)

B05-3 14:20 **Microwave Far-Field Nondestructive Detection and Characterization of Disbonds in Concrete Structures**
M.T. Ghasr, N. Qaddoumi, Sharja (Unitet Arab Emirates)

B05-4 14:40 **Characterization of Cement-Based Materials Using Microwave Reflection and Transmission Measurements**
S.N. Kharkovsky, C.D. Atis, U.C. Hazar, Adana (Turkey)

B05-5 15:00 **Microwave Imaging with Atomic Force Microscopy**
M. Tabib-Azar, Cleveland (USA)

15:20 Coffee break

EDDY CURRENTS

A06

A06-1 15:50 **Nondestructive Online Characterization of Steel Sheets by Harmonic Analysis**
B. Heutling, A. Krys, L. Grube, W. Reimche, F.W. Bach, Hannover (Germany)

A06-2 16:10 **Application of MWM™ Eddy Current Technology during Production of Coated Gas Turbine Components**
T. Beck, R. Wilkenhöner, Berlin (Germany); N. Goldfine, V. Zilberstein, Boston (USA)

A06-3 16:30 **Structure Characterization by Eddy Current Method**
M. Zergoug, N. Boucherou, G. Kamel, S. Lebaili, A. Benchaala, Alger (Algeria)

A06-4 16:50 **Determination of Small Electric Conductivity Variation by Eddy Currents**
M. Zergoug, A. Hammouda, A. Haddad, S. Lebaili, A. Benchaala, Alger (Algeria)

A06-5 17:10 **Optimisation a Digital Methods Processing of Pulsed Eddy Current**
M. Zergoug, A. Haddad, A. Hammouda, S. Lebaili, A. Benchaala, Alger (Algeria)

A06-6 17:30 **Interactions of Lateral Electromagnetic Waves at Microwave Frequencies with Metallic Surfaces**
J. Yotsuji, J.B. Spicer, Baltimore (USA)

17:50 End of session

RADIOGRAPHY AND TOMOGRAPHY

B06

B06-1 15:50 **Use of 3D Micro Tomography for the Investigation of the Mechanical Properties of Cellular metals**
E. Jasiuniene, B. Illerhaus, J. Goebbels, Berlin (Germany)

B06-2 16:10 **Characterization of Materials Structure by Dynamic Tomography**
G.-R. Tillack, J. Goebbels, B. Illerhaus, Berlin (Germany); V. Artemiev, A. Naumov, Minsk (Belarus)

B06-3 16:30 **Investigating Ballistic Impact Damage in Light-weight Ceramic Armor Designs using Advanced Computed Tomography**
W.H. Green, N.L. Rupert, J.M. Wells, Aberdeen Proving Ground (USA)

B06-4 16:50 **Reduction of Beam Hardening Artifacts in X-ray Microtomography Data**
H.-A.Crostack, J. Nellesen (Speaker), Dortmund (Germany)

B06-5 17:10 **The Use of X-ray Computed Tomography in Quantifying Air Voids in Asphalt Compacted Specimens**
H.H. Saleh, McLean; E. Masad, Pullman (USA)

17:30 End of session

MAGNETIC METHODS A07

A07-1 8:00 **Absolute Electrical Property Imaging Using High Resolution Inductive, Magnetoresistive and Capacitive Sensor Arrays for Materials Characterization**
N. GOLDFINE, A. WASHABAUGH, V. ZILBERSTEIN (SPEAKER), D. SCHLICKER, Y. SHEIRETOV, D. GRUNDY, M. WINDOLOSKI, WALTHAM (USA)

A07-2 8:20 **Characteristique determination of XC 48 treated thermally by Barkhausen noise**
M. ZERGOUG, N. BOUCHEROU, G. KAMEL, S. LEBAILI, A. BENCHAALA, ALGER (ALGERIA)

A07-3 8:40 **Dynamic Magnetostriction of Material Characterization of Micro Structure States of Degraded Structural Steel**
S. PIRFO, PETTEN (NETHERLANDS); K. SZIELASKO, I. ALTPETER, G. DOBMANN, SAARBRÜCKEN (GERMANY)

A07-4 9:00 **Micromagnetic NDE Techniques for the Characterization of Precipitation-Induced Embrittlement of 15 NiCuMoNb 5 (WB 36) Steel**
I. ALTPETER, G. DOBMANN, K.SZIELASKO, SAARBRÜCKEN (GERMANY)
presented by M. Parlog, Saarbrücken

A07-5 9:20 **Barkhausen Noise Investigation of Stress-Dependent Magnetic Properties Changes around Interacting Defects Geometries in Mild Steel**
C. MANDACHE, L. CLAPHAM, KINGSTON (CANADA)

A07-6 9:40 **In-Situ NMR Study of Dynamical Behavior of Point and Line Defects during Deformation of Materials**
K.L. MURTY, ARLINGTON (USA)

10:00 Coffee break

THERMAL CHARACTERIZATION B07

B07-1 8:00 **Thermographic Signal Reconstruction for Enhanced Characterization of Materials**
S.M. SHEPARD, J.R. LHOTA, D. WANG, T. AHMED, B. RUBADEUX, B. CHAUDHRY, FERNDALE (USA)

B07-2 8:20 **Development in Thermosonic NDE Technique**
X. HAN, L.D. FAVRO (SPEAKER), R.L THOMAS, DETROIT (USA)

B07-3 8:40 **Finite-Element Analysis Assisted by Stress Measu rement Using Infrared Thermography**
E. UMEZAKI, T. SUZUKI, SAITIMA (JAPAN)

B07-4 9:00 **Dopant profiling in silicon wafers by fourier transform infrared spectroscopy**
L. ZENI, AVERSA (ITALY); R. BERNINI, G. BREGLIO, A. CUTOLO, A. IRACE, G. PERSIANO (ITALY)

B07-5 9:20 **Thermal non-destructive testing in temporal and frequency domain**
S. BELATTAR, A. OBBADI, A. TMIRI, S. SAHNOUN, EL JADIDA (MAROC)

B07-6 9:40 **Thermography Shows Damaged Tissue and Cavities Present in Trees**
A. CATENA, ROME (ITALY)
presented by V.Bucur, Vandoeuvre les Nancy (France)

10:00 Coffee break

OPTICAL CHARACTERIZATION

A08

A08-1 10:30 **Use of Ultrasonic Excitation for Speckle Interferometry Deformation-Measurements**
H. GERHARD, G. BUSSE, STUTTGART (GERMANY)

A08-2 10:50 **Multiple Beam Interferometry and Super-Resolution**
J.B. GOODELL, BALTIMORE (USA)

A08-3 11:10 cancelled

A08-4 11:30 **Laser Pumped Fluorescence for Detection of Thermal Damage**
P.J. KULOWITCH, W.R. SCOTT, PATUXENT RIVER (USA)

A08-5 11:50 **Non Destructive Inspection and Safety Evaluation of Inside Crack by ESPI**
K.S. KIM, KWANGJU (SOUTH KOREA)

A08-6 12:10 **Fundamentals and Applications of Optical Interferometry as Quantum NDT Tools for Monitoring and Measuring Electrochemical Properties of Metals in Aqueous Solutions**
K. HABIB, SAFAT (KUWAIT)

12:30 End of session

19:30 Reception and Conference dinner
at OPERNPALAIS Unter den Linden

PLENARY A09

A09-1 **The Importance of Imaging in Nondestructive Characterization of Materials**
8:30 R.E. Green, Jr., Baltimore (USA)

A09-2 **Acoustic Imaging for Materials Characterization**
9:10 B.B. Djordjevic, Baltimore (USA)

9:50 Coffee break

AEROSPACE MATERIALS A10

A10-1 **NDE of Thermal Barrier Coatings**
10:20 A. Fahr, B. Rogé, J.S.R. Giguère, K.I. McRae, Ottawa, (Canada)

A10-2 cancelled
10:40

A10-3 **Nondestructive Characterization of Lattice Block MaterialTM**
11:00 K.G. Lipetzky, J.M. Warren, West Bethesda (USA)

A10-4 **X-Ray Computed Tomography for Solid Rocket Motors**
11:20 D.R. Wickham, Hill AFB (USA)

A10-5 **Comparing Thermography and X-Ray Computed**
11:40 **Tomography Analyses of Composite Ballistic Helmets**
W.H. Green, N.L. Rupert, C.G. Pergantis, Aberdeen Proving Ground (USA)

12:00 Lunch break

CIVIL STRUCTURES B10

B10-1 **Analysis of Crack Distribution and Propagation in**
10:20 **Concrete Using X-Ray Computed Tomography**
H.H. Saleh, R.A. Livingston, McLean (USA); A. Azam, Maryland (USA)

B10-2 **Development of a Phased Array Transmitting**
10:40 **Equipment for Ultrasonic Testing of Concrete**
F. Mielentz, M. Krause, H. Wüstenberg,
H. Wiggenhauser, Berlin (Germany)

B10-3 **Inelastic Neutron Scattering Measurement of**
11:00 **Pozzolan Performance in Portland Cement**
R.A. Livingston, W. Bumrongjaroen, D. Neumann, McLean (USA)

B10-4 **Autoradiographic Measurement of Potassium**
11:20 **Distribution in Portland Cement Concrete**
R.A. Livingston, H.H. Saleh, McLean (USA); M.S. Ceary,
A.M. Amde, Maryland (USA); M.S. Unterweger (USA)

B10-5 **The Quality Assurance Handbook as a usefull Instrument for the Practice**
11:40 G.V.M. Teodoru, Köln (Germany); J. Herf, Leverkusen (Germany); D.N. Celenti, AT&T-Labs. (USA)

12:00 Lunch break

MATERIALS CHARACTERIZATION I — A11

A11-1 13:30 **Non-Destructive Prediction of Material Properties of Steel and Al-Alloys – State and Challenge**
E. Schneider, G. Dobmann, W.A. Theiner, Saarbrücken (Germany)

A11-2 14:10 **Non-Destructive Case Depth Measuring and Monitoring**
W. Morgner, Eichenbarleben (Germany); F. Michel, K.-O. Prietzel, Magdeburg (Germany)

A11-3 14:30 cancelled

A11-4 14:50 **Evaluation of Stresses in Components Using Ultrasonic and Electromagnetic Techniques**
E. Schneider, W.A. Theiner, Saarbrücken (Germany)

A11-5 15:10 **Microscopic Characterization of Technical Magnetic Materials by Photothermally Modulated Stray Fields**
A. Kloster, U. Netzelmann, J. Wang, Saarbrücken (Germany)

A11-6 15:30 **Ultrasonic Inspection of Interfacial Adhesive Bonding in Thin Metal-Metal Sheets**
F. Severin, B. O'Neill, E. Maeva; B.B. Djordjevic, Baltimore (USA); R.G. Maev, Windsor (Canada)

15:50 End of session

PROCESS CONTROL — B11

B11-1 13:30 **New Development in Acoustic Imaging Inspection and Materials Evaluation for Vehicle Quality Control**
R.G. Maev, Windsor (Canada)

B11-2 14:10 **Evaluation of the Cure Behaviour of Epoxy Resin Using Rheometric and Ultrasonic Techniques**
J. McHugh, W. Stark, J. Döring, Berlin (Germany)

B11-3 14:30 **Rubber Processing Monitored by Ultrasound**
W. Stark, J. Döring, J. Kelm, Berlin (Germany)

B11-4 14:50 **Methods of Analysis of Dielectric Cure Monitoring Data for Process Optimisation**
M.C. Kazilas, A.A. Skordos, I.K. Partridge, Cranfield (UK)

B11-5 15:10 **Integrated Endoscopy – Bridging the Gap between Diagnosis and Action**
W. Ohnesorge, Knittlingen (Germany)

B11-6 15:30 **On-line Methods for the Determination of Mechanical Properties - State of the Art and Critical Assessment of Measurement Uncertainty**
M. Borsutzki, O.-W. Buchholtz, U. Paul, Duisburg (Germany)

15:50 End of session

MATERIALS CHARACTERIZATION II — A12

A12-1 8:00 **Survey on NDE of Non-Metallics**
G. Busse, Stuttgart (Germany)

A12-2 8:40 **Review of Nuclear Magnetic Resonance for Nondestructively Characterizing Materials**
G.A. Matzkanin, Austin (USA)

A12-3 9:00 **Nondestructive Characterization of Polymers with NMR in One-Sided Access Technique**
B. Wolter, F. Kohl, N. Surkowa, Saarbrücken (Germany)

A12-4 9:20 **Non-Contact and Non-Destructive Strain Measurement in Composites**
S.A. Vierkötter, D.M. Gregory, S. Menon, San Diego (USA)

A12-5 9:40 **A Novel Technique for Pore Structure Characterization without the Use of any Toxic Material**
A. Jena, K.Gupta, New York (USA)

10:00 Coffee break

COMPOSITES — B12

B12-1 8:00 **Acoustic Studies of Composite-Material Interfaces**
H. Ledbetter, Boulder (USA)

B12-2 8:20 **Micro Cracking and Stress State under Fatigue Loading of CFRP**
V. Trappe, K.-W. Harbich, H. Ernst, Berlin (Germany)

B12-3 8:40 **Characterization of Damage Accumulation During Fatigue in Fibre Reinforced Thermoplast by X-Ray Refraction**
H.-V. Rudolph, M.P. Hentschel, H. Ivers, K.-W. Harbich, Berlin (Germany)

B12-4 9:00 **Ultrasonic Characterization of Fatigue Cracks in Composite Materials**
G.L. Workman, J. Watson, D. Johnson, Huntsville (USA); J. Walker, S. Russell (USA)

B12-5 9:20 **Interface Damage Growth Monitoring in Polypropylene Thermoplastic Composites**
A. Maslouhi, E. Kamal, I. Ndiayé, Moncton (Canada)

B12-6 9:40 **Characterization of the Fatigue Damage of Advanced Ceramic Composites by Scanning Acoustic Microscopy**
M.H. Manghnani, P. Zinin, Y. Wang, Honolulu (USA); V. Levin, Moscow (Russia)

10:00 Coffee break

MATERIALS CHARACTERIZATION III A13

A13-1 10:30 **Nondestructive Evaluation of Elastic and Piezo-electric Properties of Ferroelectrics Using Atomic Force Acoustic Microscope and Piezo-Mode Techniques**
M. Kopycinska, U. Rabe, C. Ziebert, H. Schmitt, S. Hirsekorn, W. Arnold, Saarbrücken (Germany)

A13-2 10:50 **Qualitative New Mechanical Properties of Micro-structured Metallic Systems**
J. Schreiber, V. Melov, Dresden (Germany)

A13-3 11:10 **Elastic-Stiffness Tensor of a Single SIC Fiber at Elevated Temperatures**
H. Ogi, S. Kai, T. Ichitsubo, M. Hirao, Osaka (Japan); K. Takashima, Yokohama (Japan)

A13-4 11:30 **Anisotropic Elastic Constants of Unidirectional Porous Copper Measured with Resonance Ultrasound Spectroscopy**
T. Ichitsubo, M. Tane, H. Ogi, M. Hirao, T. Ikeda, H. Nakajima, Osaka (Japan)

A13-5 11:50 **Nondestructive Detection and Characterization of Kirkendall Voids in Clad Metals for Micro-batteries Using Ultrasonic Method**
H. Baskan, H. Kawate, T. Ishii, K. Sekine, Yokohama (Japan); M. Ishio, Suita (Japan)

A13-6 12:10 **Reference Blocks Problem for Type Testing of Penetrant Systems**
N.P. Migoun, P.P. Prokhorenko, A.B. Gnusin, Minsk (Belarus); M. Stadthaus, H.-M. Thomas, Berlin (Germany); J. Baugatz, W. König, Hannover (Germany)

12:30 Closure

SURFACES AND BONDS B13

B13-1 10:30 **Non-destructive Testing of Thermal Barrier Coatings by Impedance Spectroscopy**
T. Hilpert, E. Ivers-Tiffée, S. Wagner, R. Oberacker, Karlsruhe (Germany)

B13-2 10:50 **In-Situ Characterization of Dry Surface Contact Using Ultrasound**
C. Byrne, Bowling Green (USA)

B13-3 11:10 **Contactless Characterization of Coatings with a Microwave Radar Sensor**
C. Sklarczyk, Saarbrücken (Germany)

B13-4 11:30 **Photoacoustic Nondestructive Quality Control of Microwelded Connection of Semiconductor Devices and Integrated Circuits**
O. Vertsanova, Kiev (Ukraine)

11:50 End of session

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11TH INTERNATIONAL SYMPOSIUM
NONDESTRUCTIVE CHARACTERIZATION OF MATERIALS™
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HOW TO FIND AN ABSTRACT

11TH INTERNATIONAL SYMPOSIUM ON
NONDESTRUCTIVE CHARACTERIZATION OF MATERIALS™
JUNE 24-28, 2002, BERLIN, GERMANY

ALL ABSTRACTS

A laser ultrasound / EMAT imaging system for near surface examination of defects

R. J. Dewhurst, S. Boonsang, P.R. Murray.
Department of Instrumentation and Analytical Science, UMIST, Manchester

This presentation reports on recent advances in laser ultrasound measurement systems for imaging near surface defects, or for the imaging of buried defects. A portable system is described that utilises nanosecond ultrasound for material interrogation. It uses Nd:YAG laser pulses with energies of about 15 mJ to produce thermoelastic ultrasound. The pulses are delivered to the material surface via an optical fibre and focused to a line source by a cylindrical lens within a scanning head. Uniquely, this same head contains a miniaturised EMAT receiver, separated by a fixed distance from the optical fibre. In combination, they are able to scan a sample surface. Signal capture and processing routines are used to generate B-scan images of the test sample. A range of ultrasonic modes is simultaneously produced using this method. These include surface skimming longitudinal (L_s), Rayleigh waves, bulk longitudinal (L) and bulk shear (S) waves.
In our present system, the electromagnetic acoustic transducer (EMAT) is sensitive to in-plane ultrasonic signals. Transient acoustic fields generated by the interaction of the Rayleigh waves with surface-breaking defects provide important information on the position and geometry of the defect. B-scan images are exploited to visualise any changes of interrogating acoustic waves due to the presence of a defect. Images are produced by traversing the non-contact scanning head across the material's surface, with return signals that are colour-coded to form a 2D acoustic map. A series of lines are identified as reference acoustic waves. Typically B-scan images have been obtained by the compilation of 250 A-scan waveforms, and a range of images will be presented. They will show both acoustic images from surface defects and the effects of side-wall reflections. Some factors affecting resolution will be discussed. This instrumentation system is portable and shows the basis of a laser/EMAT imaging system for effective materials characterisation.

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programme no. **A01-1**

Ultrasonic Technology for Characterizing Laser Damage in Optics

Graham Thomas, L. Peter Martin, Dave Chambers
Lawrence Livermore National Laboratory

An ultrasonic technique was developed to detect and characterize laser damage in critical optics. During otherwise normal usage, sub critical flaws induced by the high laser fluence can grow to critical size and potentially can cause unanticipated failure of the optics. The ultrasonic system monitors the optic in situ and will provide a quick, reliable way to quantify the location, number and, ultimately, the size of defects that may initiate and grow during firing of the laser.

The feasibility of detecting, sizing and even deploying an ultrasonic technology was demonstrated. This demonstration included modeling the acoustic interaction with damage in the optic, building prototype electronics, acquiring prototype transducer arrays, fabricating damaged optics, and developing sophisticated signal processing algorithms. The modeling aided the configuration of the ultrasonic transducers and electronics. It also helped us to build the signal processing algorithms and ultimately characterize the damage sites. Two types of damage were fabricated. First machined in damage was placed in an optic at various locations and size. These samples helped demonstrate the potential of the technique and calibrate the sizing method. Secondly, ultrasonic data was acquired in situ on an optic as it was being damaged by a laser. Signal processing algorithms were developed to analyze the ultrasonic data and detect and size the damage sites. This second task clearly demonstrated the potential for ultrasonic monitoring of critical optics for laser-induced damage.

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programme no. **A01-2**

Laser-Air Hybrid Ultrasonic Technique for the Inspection of Rail Steel.

Shant Kenderian, B. Boro Djordjevic, Robert E. Green, Jr.
The Johns Hopkins University
Materials Science and Engineering Department
Baltimore

Laser-based and air-coupled ultrasound technology was combined for the inspection of rail tracks and wheels for internal and surface-breaking cracks. Signals were generated with an IR pulse laser and detected with a micromachined capacitive air-coupled transducer. Multimode signals were generated with a single pulse and the rail was inspected for more than one type of defects simultaneously. A comparison is presented between point source and line source laser generated signals and their effectiveness in detecting surface flaws. The experiments demonstrate the flexibility and capability of a Laser-Air Hybrid Ultrasonic Technique to detect cracks using test procedures that are not possible with current contact inspection techniques. The noncontact and remote nature of these methods renders such tests suitable for in-service applications for a variety of structural materials.

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programme no. **A01-4**

Laser-Ultrasonics Monitoring of LC Steel Absorption During Annealing

Silvio E. Kruger and Stéphane Bolognini
IMI-National Research Council of Canada

A laser-ultrasonic reverberation technique is used to monitor the ultrasonic absorption during annealing of low carbon steel. Small samples (about $1x10x10mm^3$) of cold rolled (80% reduction) low carbon steel (0.05%C wt) are annealed at temperatures of 570°C, 600°C and 620°C. The ultrasonic absorption is obtained by the Joint Time Frequency Analysis (JTFA) of the reverberated ultrasonic waves generated and detected by lasers. The damping of the waves bouncing inside the sample is attributed to ultrasonic absorption since the laser- ultrasonics technique is non-contact and no important acoustic energy leaking is present. Room temperature measurements under magnetic field show that the dominant absorption mechanism is of magnetoelastic origin. Results show a monotonic increase of the absorption during the annealing. The low dislocation density structure of the annealed samples allows easier magnetic domain walls motion and is the main source of the absorption increase. Under saturating magnetic field, when the magnetoelastic contribution to absorption is suppressed, the annealed samples present a different absorption frequency dependence compared to the cold rolled samples. This suggests different non-magnetic absorption mechanisms between annealed and unannealed samples. Correlations of ultrasonic absorption with the metallographically evaluated recrystallized fraction as well as with hardness are reported.

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Characterization of steels with ultra-fine grain by ultrasonic measurement using laser ultrasonics

Hisashi YAMAWAKI, Akio OHOMORI and Tetsuya SAITO
National Institute for Materials Science, Japan

Measurement of elastic anisotropy of materials is expected as method to evaluate, indirectly, various mechanical properties of materials. For the measurement of elastic anisotropy, ultrasonic velocity measurement is utilized, and laser ultrasonic technique is suitable for the measurement, because it is free from coupling medium of ultrasound and applicable for small region. In experiments, laser ultrasonic technique with pico-second pulse laser for ultrasonic short pulse generation, and two-wave mixing interferometer with photo-refractive crystal for high frequency ultrasonic detection on rough surface of specimen was used for precise measurement of ultrasonic anisotropy of steels with ultra-fine grain size (< 1 micron) produced by various making processes.

As results of the measurement, anisotropy of longitudinal and surface ultrasonic waves were obtained, and those indicated microstructure of the steels shows strong elastic anisotropy, and difference of the microstructures made by the various processes shows remarkable difference in elastic anisotropy. For example, steels made with same elements, and made by same mechanical process (groove rolling) in different processing temperature, showed different grain size and different tensile strength, have evident relation between grain size and elastic anisotropy between rolling direction and traverse direction. In conclusion, it was induced that ultrasonic anisotropy measurement has capability for evaluation of mechanical properties such as tensile strength brought by microstructures of the steels.

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programme no. **A01-6**

Negative Poisson's ratios in wood and particleboard with ultrasonic technique

Bucur V. , Kazemi Najafi S.

The Poison's ratio is defined as the ratio of lateral strain to the longitudinal strain during the loading of an isotropic specimen in tension. It is generally accepted for the isotropic solids that the Poison's ratio is about 0.3 and always positive.

For the anisotropic solids the measurement of Poisson's ratios is a complicated task and static or dynamic methods have been used. Indeed, negative Poisson's ratios or values >1 for anisotropic solids may contradict intuition if the majority of experience is in isotropic solids. Negative values have been reported in anisotropic solids such as : composites, foams, crystals or alloys and has been measured when the body expands laterally under tension. This behavior is probably due to the specific disposition of the microstructure, as for example the honeycomb pattern.

The aim of this article is to determine the Poisson's ratios of wood and particleboard with ultrasonic technique, when the hypothesis of orthotropic symmetry is considered.

The determined Poisson ratios have been ranging between -0.06 and + 1.32 for particleboard and -0.095 and 1.664 for wood.

The validity of these numbers has been demonstrated with the relations between the terms of the stiffness matrix, compliances and Young's moduli and shear moduli, that must be positive.

Key words :
ultrasonic technique, anisotrpic solids, Poisson's ratios, wood, particleboard

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Characterization of plastically deformed steel utilizing EMAT ultrasonic velocity measurements

P. D. Panetta[1], A. Diaz[1], R. A. Pappas[1], B Francini[1], K. Johnson[1], and George Alers[2]
[1]Pacific Northwest National Laboratory
[2]EMAT Consulting

There is a desire to characterize plastically deformed regions in structures to monitor their integrity. Of particular importance is the accurate prediction of the lifetime of damaged pipelines due to outside force. In order to accurately predict the remaining life it is essential to accurately determine the degree stress and strain in the damaged region for input into fracture mechanics models. Currently, determination of the degree of stress and strain in damaged regions utilizing ultrasonic velocity measurements is complicated by the inherent texture in the materials and the difficulty in separating these effects from the stress and strain contributions. We will report ultrasonic velocity measurements on plastically deformed steel specimens to elucidate the state of damage. Specifically, we have found the shear wave birefringence is sensitive to the degree of plastic deformation. Ultrasonic determinations of the damage levels will be compared with finite element modeling calculation of the stress and strain distributions.

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programme no. **A02-2**

A mixed-spectral method for exact measurement of phase velocity of multi-mode Lamb waves

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In Lamb wave testing for industry applications, the Lamb waves are excited usually by a shot pulse applied by a transducer, therefore, multiple modes of Lamb wave are always in structures and these modes are generally dispersive. In order to obtain useful information from a Lamb wave detection system, it is necessary to determine the velocity of individual Lamb wave mode while suppressing coherent turbulence due to other modes of Lamb wave propagation. Some workers have proposed several techniques based on a two-dimensional Fourier transform or wavelet transform for the analysis of propagating multi-mode signals. However, if it is necessary to measure the phase velocities of multi-mode signals exactly, or those multi-mode signals whose wave-numbers are very close, it may not be possible to get the correct results by using 2-D FFT and wavelet transform, since its spatial resolution is not strong enough.

In order to improve the revolution a mixed-spectral estimation is proposed to combine with FFT and auto-regressive (AR) model for exact detection of phase velocity of multi-mode Lamb waves. When Lamb wave propagates along surface (in x direction) of a plate, surface displacement is $U(n_x,n_t)$, the discrete mixed-spectral expression can be given as:

$$H_1(n_x,e^{i\omega}) = \sum_{n_t=1}^{N_t} U(n_x,n_t)e^{-i\omega\, n_t} \tag{1}$$

$$H_{AR}(e^{iw}) = \frac{\sigma^2 \Delta t}{\left|1+\sum_{k=1}^{p} a_k e^{-i\omega k}\right|^2} \tag{2}$$

where, ω is angle frequency, n_t is discrete time sequence, n_x is discrete spatial sequence, N_x is the length of discrete spatial sequence, Δt is sampling interval, σ^2 is variance of exciting white noise, a_k is model coefficient, p is the order of AR model. Both σ^2 and a_k can be easy calculated from $H_1(n_x,e^{i\omega})$.

Because of its strong spatial resolution, this new approach can differentiate the Lamb wave modes whose wave-numbers are very close that two-dimensional fast Fourier transform (2-D FFT) can't tell apart them, and estimate accurately the phase velocities of the modes. Some experimental results shown that the method has a good performance for exact measurement of phase velocity of multi-mode Lamb waves.

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programme no. **A02-3**

Wood slowness surfaces in tridimensional representation

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Mechanical behaviour of wood considered as an orthotropic solid can be determined with ultrasonic technique. The propagation phenomena in wood are complex and theoretically are regulated by Christoffel's equation. Three type of waves can propagate in wood. During the propagation phenomena three slowness sheets are observed, corresponding to a fast longitudinal wave (inner sheet) and to two shear waves, one fast and one slow (outer sheet). These waves are submitted continuously to mode conversion phenomena. The polarization angle changes when the propagation direction is out of principal directions of symmetry of the material. In this article an analysis of the propagation phenomena in tridimensional representation is performed for six species. Tridimensional slowness surfaces were represented to illustrate the acoustic properties of six species (spruce of commun structure , resonance spruce, Sitka spruce, tulip tree oak and curly maple) This approach contributes to the understanding of dynamic aspects of particle displacement associated with the wave fronts propagation. Globally, the anisotropy of each species, expressed by their acoustical behaviour is well represented .

Keywords: *Wood acoustic properties; Ultrasonic waves ; Slowness surfaces; Anisotropy*

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Analysis of laser-generated Lamb waves with wavelet transform

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Lamb waves have been proved to be very efficient for nondestructive testing of plate-like structures. The problems associated with the use of Lamb waves for structure inspection are coexistence of several modes at each frequency and their dispersive nature. Stress waves generated by a single laser pulse, because of its broadband nature, can produce a wide number of vibrational Lamb modes in a plate. Overlapping of Lamb waves in the time domain may make signal interpretation very difficult. Lamb wave inspection can be performed either by generating a single Lamb wave so that signal interpretation is made easier or by analyzing the multimode Lamb waveform with wavelet transform. The standard frequency analysis of an ultrasonic signal by Fourier transform determines the different frequency components without considering their temporal order. Wavelet transform gives the frequency-time representation of a broadband multimode time domain signal. Continuous wavelet transform is defined as the inner product of the signal x(t) with the function $\psi_{a,b}(t)$, called the mother wavelet. The mother wavelet is the transforming function and is function of two variables, a and b, the time scaling and time shift parameter, respectively. Wavelet analysis of a signal gives a series of wavelet coefficients; each coefficient for a set of the scale and shift parameters. Wavelet coefficients represent a correlation between the signal x(t) and the mother wavelet $\psi_{a,b}(t)$. When the signal is similar to the wavelet, coefficients are high. Such coefficients are usually represented as a color level map on a frequency-time. There are different types of wavelets and appropriate selection must be made for ultrasonic signal analysis.

Wavelet transform is used to analyze Lamb waveforms, excited by a single-shot laser pulse, propagating in composite and aluminum plates. Different Lamb modes obtained by wavelet transform of signals from defect-free and defective regions provide an effective way to locate defects. Results indicate that wavelet transform is extremely useful for identification of Lamb modes in a multimode Lamb waveform. Moreover, group velocity dispersion curves can be obtained from the arrival time of each wave component as a function of frequency.

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programme no. **A03-1**

Ultrasonic quantitative NDE of defect in plate structure using multi-mode Lamb waves

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Lamb wave NDE technique receives more and more attentions because of their higher inspection efficiency than traditional bulk wave technique. In recent years Lamb waves in plates have been studied extensively. However, for successful use of this technique in industry, some essential work needs to be done in order to develop approach for sizing defect. In this paper, numerical calculation and experiment validation with multi-mode Lamb waves are achieved for quantitative NDE of defect in plate.

A hybrid boundary element method combined traditional boundary element method with Lamb wave normal mode expansion technique is developed to solve scatter behavior of Lamb wave by surface defects in plate. Some relations between frequency and Lamb wave mode of incidence and depth of defects are obtained. The variations of transmission and mode conversion factor of different Lamb waves, which point the magnitude of energy of different modes, are calculated numerically in this work. The numerical results indicate that multi-mode Lamb waves can be used to identify the depth of surface defect in plate.

Experiments with several surface defects in 1.44-mm-thick aluminum plate were tested under condition of pulse ultrasound in order to obtain multi-mode Lamb waves. Two different angel broadband transducers by central frequency at 1.0 MHz, with it either A_0 or S_0 mode could be generated stably, were selected as sender. A 45° angel broadband transducers by central frequency at 1.0 MHz, with it both A_0 and S_0 mode could be received, were acted as receiver. Lamb wave transmission and mode conversion were observed in experiments, when a Lamb wave mode propagated through surface defects in plate. Some signal variation of received A_0 and S_0 mode amplitude with the change of defect depths were obtained. The experiment results verify that the surface defect depths in plate can be quantitatively determined with the ratio of A_0 and S_0 Lamb wave mode amplitude.

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programme no. **A03-2**

Non-Contact Flaw Detection in Thin Plates using Various Modes of Lamb's Wave with Laser Ultrasonics

Morimasa Murase and Koichiro Kawashima*

Most nondestructive evaluation of thin plates and thin-walled pipes with guided waves utilizes only the fundamental modes, in particular S_0 or A_0 for plates and L(0, 1) or L(0, 2) for pipes due to the weak dispersion. Some types of defect in thin plates are not sensitive to the mode, therefore, the use of the higher modes is preferable. However, defect detection with the time domain signals of the higher modes is quite difficult due to the strong dispersion.

Signal processing, such as phase spectrum method or wavelet transformation, of the waveforms of multi-mode Lamb's waves can identify a particular mode of Lamb's waves and determine the group velocity dispersion of the mode.

Various modes of the Lamb wave were excited by YAG laser for aluminum plates of 2mm thick and were detected by a heterodyne laser interferometer at a certain distance from the excitation. Wavelet transformations of the received waveforms on a plate with and without a slot are compared. For the plate of a slot of 0.5mm deep and 40mm wide, the group velocity dispersion curves of S_1, A_1 and A_2 modes in low velocity range show higher velocity than the slot free plate. Also, the S_0 dispersion curve in the range of 1- 2.5 in frequency□thickness nearly disappears. By knowing the dependence of the dispersion curve distortion on defect patterns, we will be able to identify the defect in thin plates.

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programme no. **A03-3**

Identification of Subsurface Void Size and the Depth in Ceramics with Frequency Spectra of Leaky Rayleigh Wave

Koichiro Kawashima*, Toshihiro Ito, Ryuji Omote and Yoichi Hattori

FEM simulation for identification of void size and the depth was performed for a subsurface spherical void within ceramics by using leaky surface wave.

Subsurface voids of some 50 μm in diameter within ceramics can be nucleus of bending fracture. Conventional C-scan acoustic microscope can't detect such voids, because the surface reflection masks the echo from the voids. A surface wave technique using only the leaky Rayleigh wave can detect such voids, however, the sizing of voids is difficult because the wave amplitude depends on the voids size and their depth.

Surface wave propagation simulation using finite element method was applied for subsurface voids within silicon nitride ceramics. The void sizes normalized by the wavelength of the Rayleigh wave are 0.3-0.6 and the dimensionless depths are 0.4- 0.75. The amplitude spectra of the received leaky Rayleigh waves were normalized by that of a void free sample of the same material. The amplitudes and frequencies at the bottoms of the spectra have shown to be functions of the void size and the depth. Thus, the void size and the depth are estimated by functions of the normalized amplitude and frequency normalized by the peak frequency of the void free sample. The simulated results were confirmed by the measurement on silicon nitride samples having voids at various depths with a surface wave transducer of 50 MHz.

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programme no. **A03-4**

Optimization of Lamb Wave Flaw Sensitivity Using Phased Array Excitation

Michael J. Quarry

An ability to tune to a mode with maximum flaw sensitivity is essential to effective guided wave inspection of plates. A variable angle beam and a comb transducer with variable spacing are two approaches to perform mode tuning. These approaches can be difficult to implement in an efficient manner. This study focuses on the development of a multi-channel phased array transducer system. The approach is more practical and efficient for developing a general guided wave inspection technique, capable of inspecting structures of various materials. A multi-channel arbitrary waveform pulser system is used to drive an array to tune to modes that optimize flaw sensitivity. The phase velocity spectrum of the output of the transducer is computed theoretically using complex reciprocity and normal mode expansion. Analysis of the phase velocity spectrum enables the development of an algorithm for sweeping through the dispersion curves. Experimental results show that tailoring the phase velocity spectrum of the array can quickly find modes with optimal sensitivity. The results show that the flaw sensitivity of Lamb wave modes may be optimized by experimentally sweeping through modes via the phased array system.

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programme no. **A03-5**

Excitation of thin plate vibrations by laser pulses

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**General Physics Institute, Russian Academy of Sciences,

Excitation of thin plate vibrations by laser pulses of arbitrary shape is considered theoretically. The following restrictions are applied: a pulse is positive and the pulse envelope satisfies the existence conditions of integrals and summation of series. It is assumed that laser radiation is absorbed in the plate surface layer with the thickness much smaller than the plate thickness. The distribution of laser radiation at the plate surface is described by the Gaussian law. Particular features of plate vibrations in the far wave field are analyzed for the cases of "long" and "short" laser pulses.

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programme no. **A03-6**

Ultrasonic Attenuation and Backscattering in Duplex Alloys for Materials Characterization

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It is well known that the microstructure can affect a propagating ultrasonic beam. For example, the sound velocity is significantly affected by crystallographic texture. In addition, during flaw detection, the microstructure can backscatter energy, creating noise which can mask signals from small flaws. Furthermore, a flaw signal can be attenuated by absorption and scattering of energy. These effects can have deleterious effects on flaw detection and characterization. However, due to the link between backscattered grain noise, attenuation and the microstructure, measurement of these ultrasonic quantities can be used as accurate materials characterization methodologies if appropriate models exist. Theoretical predictions of attenuation have been made successfully in the past in materials consisting of texture free, equiaxed grains. However, there is a lack of adequate models describing the attenuation and backscattering in duplex alloys with texture such as commonly used steels and titanium alloys. The multiple scattering, which controls the attenuation, is of particular interest. In this paper, we will present theoretical predictions and experimental measurements of attenuation and backscattering in duplex alloys, with the practical goal of producing a theory to quantify material properties when coupled with appropriate ultrasonic measurements.

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Ultrasound Laminography – A new method to detect deterioration of materials an creep load

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By creep load of high pressure – high temperature steam pipes mainly of power plants life time and reliability of these components are limited. So it is an important requirement to measure the change of materials properties depending from inservice time and to assess the run down of life time. Nowadays for this purpose the judgement of the grain structure by the mean of ambulant metallographic replica technique is introduced. This however is a relatively expansive procedure which includes only small surface areas of the supervised component. So many attempts had already been made to define the change of materials properties under creep conditions by the mean of other non destructive testing methods. It had been regarded for this application among others electric and magnetic techniques, mainly the conductivity, measurement of sound velocity, - damping and – dispersion, thermal and ultrasonic microscopy. Up to now it was not successful to transfer these methods in the practical assessment of residual life time of steam pipes.

The reason is given by the only inferior change of the measured variables by creeping within the tolerable limits. So mainly with respect to possible scattering no absolute gauge can be used but the relative changes within the same component have to be regarded.

With the new method of Ultrasonic Laminography a very high resolution of the measurement of sound velocity can be realised. Furthermore this technique uses the fact that the influence of creeping runs forward on the outer case of a pipe bend compared with the deeper layers of the pipes wall. So reference measurements on the same component are possible.

The Ultrasonic Laminography uses continuous Rayleigh surface waves which allow an immediate scanning of the wave length and by this way to measure the sound velocity. By the use of different frequencies different layers underneath the surface of the pipes wall will be included in the measurement. Criterion for the judgement of the influence of creep load on the condition of the material is the change of the sound velocity vs. depth of the different layers in the cross section of the wall. In case of creep damages an increase of sound velocity is registered with the reaching of deeper layers. Without damages the sound velocity will show no changes from the outer case to the deeper layers.

Results of measurements in power plants will be presented and will be compared with results from replica technique. An outlook to the further development of the new technique will be given.

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Experimental and Theoretical Evaluation of Ultrasonic Attenuation in Carbon/Epoxy Composites

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Attenuation of ultrasonic waves in carbon fiber reinforced epoxy composites (CFRP) is studied experimentally and theoretically. In this study, frequency-dependent attenuation coefficients of longitudinal and transverse waves are measured by the spectral analysis of ultrasonic echoes obtained by aid of normal-incidence contact transducers. Measurements are carried out for epoxy resin and for unidirectional CFRP samples with different fiber volume fractions. For transverse waves, two polarization directions are examined which are parallel and perpendicular to the fiber direction. From these measurements, relations between the fiber volume fraction, the wave polarization direction and the ultrasonic attenuation behavior are investigated. It is found that the attenuation coefficients of CFRP are lower than those of epoxy in the practical MHz frequency range. The transverse waves are shown to exhibit higher attenuation than the longitudinal wave, while no clear difference is observed between the attenuation for the two polarization directions of the transverse waves. Also, attenuation properties of CFRP laminates with different stacking sequences are measured and compared to those of unidirectional ones. It is then found that the cross-ply and angle-ply laminates have longitudinal attenuation properties similar to unidirectional ones, but much higher attenuation than unidirectional ones for transverse waves. The attenuation characteristics of longitudinal and transverse waves are analyzed for unidirectional CFRP based on a theoretical model formulated by the authors [1, 2], which takes into account the scattering as well as absorption loss within the framework of independent scattering model combined with the differential (incremental) scheme of micromechanics. The theoretical results are favorably compared to the measured attenuation coefficients, in terms of their dependence on the frequency and the fiber volume fraction. The present findings are expected to be useful in interpreting the measured attenuation of CFRP on a sound theoretical foundation in various aspects of nondestructive materials characterization.

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Application of signal processing in ultrasonic characterization of multi-layered composite materials

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Multi-layered composite and plastic materials are widely used in various sectors of industry, for example, in aerospace. For characterization of elastic properties, geometry and integrity of multi-layered structures ultrasonic techniques may be applied. However, differently from the single layer materials, presence of other layers made of different materials significantly complicates this task. This is due to multiple reflections of ultrasonic signals, caused by interfaces between adjacent layers. These signals may overlap in the time domain, thus making characterization unreliable or not accurate enough. These problems starts to be dominating when on-line measurements for process control are carried out.

The main objective of this paper is to present the ultrasonic signal acquisition and processing techniques enabling to determine parameters of individual layers in multi-layered composite and plastic materials. This approach is based on reconstruction of ultrasound velocity and attenuation in each layer. By the ultrasound velocities here are assumed the complete set of velocities of propagating modes in the object under a test. This is an inverse task, which is an ill-posed problem. This problem is complicated by the fact that all multiple reflections may overlap in the received signal. In some simpler cases they can be separated using the cross-correlation processing and spectral analysis which may be used for the characterization of the structure. For solution of more complicated cases was proposed approach based on the iterative non-linear deconvolution. According this approach the analysis is performed step by step for each layer using the information about the previous layers. In each step the acoustic properties of the layer are recovered using numerical optimization. The recovered set of ultrasonic velocities and attenuation curves enables to characterize the dimensions and the mechanical properties of the each layer. The presented approach is illustrated by experimental results obtained for multi-layered composite (like GLARE) and plastic materials.

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Air-coupled ultrasound inspection for material characterisation in linear, non-linear, and slanted transmission mode

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New arising questions in material characterisation require improved testing techniques. One of them is air-coupled ultrasound where the difficulty of amplitude reduction by about -150 dB (because of huge impedance mismatch between air and solid) is overcome by a new commercially available equipment: it uses focused piezo-composite transducers (centre frequency 450 kHz) and sensitive electronics to enhance the signal-to-noise ratio.

We present results performed with three different kinds of measuring techniques:

First is linear air-coupled ultrasound inspection in transmission mode. Results obtained on liquid sensitive materials (e.g. wood), carbon fibre reinforced plastics, and "smart" structures are shown in this part of the paper.

Second is non-linear air-coupled ultrasound inspection, which uses non-linear behaviour of defects for defect-selective imaging. Damping not only broadens resonances, but it is also a highly non-linear process that is amplitude dependent. In addition, the out-of-plane movement of loose interfaces is non-linear and results in "clapping". Therefore, the excitation of a sample by injection of a sinusoidal wave produces higher harmonics at the damaged area. In the case of non-linear air-coupled ultrasound, the sample is excited at frequencies that have 450 kHz as a higher harmonic. When a narrow band receiver tuned to 450 kHz scans across the sample, it responds selectively to these harmonics. Defect selective imaging is used for inspection of fibre-reinforced plastics and "smart" structures in order to reveal delaminations and impacts.

Third is air-coupled ultrasound inspection in slanted transmission mode (STM) which is based on the "resonance" transmission of an acoustic wave through the sample because of Lamb mode excitation and re-radiation. By measuring the angles of maximum transmission for a weakly focused incident ultrasonic beam, the phase velocities of the zero-order symmetrical and anti-symmetrical modes were determined for various isotropic materials. Thus it is possible to detect fibre orientations of reinforced materials and of crystalline Si-wafers. These measurements in STM-mode improve also the contrast of C-scan imaging for cracks and delaminations.

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Ultrasonic testing of bonds on aluminium extruded profiles.

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The use of adhesion is increasing for a broad range of applications. Most of the focus is concentrated on the design of the products in order to have a sufficient bond area and reasonable load conditions. It is however, also necessary to look on techniques to ensure that the quality of the bonding is high and reproducible. There are many factors that control a good bonding i.e. choice of adhesion, pre-treatment of aluminium and temperature. The aim of this study is to find non-destructive techniques for testing adhesion bonds of extruded aluminium profiles.

It is well known that it can be difficult to detect a bad bonding where a good contact between adhesive and adherent is achieved but nevertheless have a low strength. The ultrasonic pulse-echo technique described in this paper is the techniques, which have proven most reliable. The ability to detect bad bonding with the use of ultrasonic waves relay on the fact that the reflection of ultrasonic wave from the interface aluminium/adhesion is dependent on the structure of the bonding. If there is a bad bonding (missing adhesion or bad contact between adhesion and aluminium) the reflection will often increase due to increased acoustic impedance and the phase of the reflected wave will change from positive to negative phase. Measuring both the positive and negative peak this shift can be measured. However the described approach is the best way of.

The technique requires the use of longitudinal waves and therefore waves perpendicular to the surface are needed. This gives some restrictions on the geometry and access to the bond area. The ultrasonic results are correlated with destructive tests and visual inspection after cutting up the specimens.

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Real-time Ultrasonic Imaging Using CCD Camera Techniques

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Ultrasonic testing of structural components is well established as one of the industry's benchmark techniques. Its capability to penetrate both thin and thick material provides arguably the best information to inspectors on subsurface faults. However, there are two basic drawbacks to its use: its complexity of use and its slow speed. Real-time Ultrasonic Imaging solves both of these issues by providing an easily understood image with high quality subsurface information about flaws and discontinuities that are observed in 1/30 second. The basis for this technology is a novel two-dimensional imaging array that creates immediate, high-resolution images of subsurface faults. Each frame, presented at TV rates or faster, presents a C-scan image over an area. Image processing performs real time video enhancement such as brightness, contrast, noise reduction, large montage images, etc. Specific discontinuities that offer a substantial potential for this technique include subsurface cracking, voids, impact damage, delaminations and corrosion.

This ultrasonic camera is composed of a sending transducer, acoustic lenses and an imaging array. The first generation imaging array was developed by modifying an infrared CCD camera to image sound waves. This technology has made it possible to perform real-time ultrasonic imaging capable of imaging discontinuities on the order of 0.1mm. The physics for the formation of images is very similar to light imaging including the use of standard programs for the design of focusing lenses. Therefore applications include both wide area inspection for larger discontinuities and small area inspection with high magnification.

This presentation will focus on the latest developments in hardware design and applications engineering including the high-speed inspection of piping and tubing and single-sided inspection of aerospace structures. Real Time Ultrasonic Imaging has already transitioned to American Industry for quality control during composite fabrication by aerospace companies and for the inspection of critical parts such as computer chips. It has been successfully adapted to image fine corrosion and cracks in aluminum; skin-to-honeycomb disbonds, crushed core, resin starvation and delaminations in composite materials; and blood vessels (etc) in human tissues.

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LISA simulations of Time Reverse Acoustics and Ultrasonics experiments

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Time Reversed Acoustics (TRA) is a new research field that has generated considerable excitement over the past few years, both as an area of basic science and for its potential application in several fields [1]. Experiments investigating TRA have been conducted in water, human tissues, flawed materials and in the ocean and are currently being performed on earth materials at the Los Alamos National Laboratory.

To complement this experimental work, numerical simulations of TRA and TRUS (Time Reversed Ultrasonics) are also performed in the framework of the Local Interaction Simulation Approach (LISA) [2]. These simulations can be useful to investigate the extension of TRA to elastic media and the optimization of the focusing procedures in waveguides and hetergogeneous media, both in cavities and with TR mirrors. They can also be used to investigate the application of the method called DORT (Decomposition de l'Operateur de Retournement Temporel) in elastic heterogeneous media. Dort allows one to decompose recorded waveforms into those that are caused not only by the strongest scatterers, but also by relatively weaker ones.

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Temperature Effect of Mechanical Damping and Anisotropic Elastic Properties of Zr-2.5Nb Pressure Tube using Resonant Ultrasonic Spectroscopy

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Temperature effect of mechanical damping factors(Q^{-1}) and anisotropic elastic constants of Zr-2.5Nb pressure tube materials were determined by a high temperature resonant ultrasound spectroscopy(RUS). Resonance frequencies were measured using a couple of Alumina wave guides and wide-band ultrasonic transducers into a small furnace. The rectangular parallelepiped specimens were fabricated along with the axial, radial, and transverse direction of the pressure tube. Higher Q^{-1} in the temperature range of 100 ~ 220°C was observed. Those Q^{-1} values increase as the hydrogen concentrations increase. There is no clear explanation of these high Q^{-1} values at this moment, but there are several possibility of; 1) a transformation of δ-zirconium hydride to γ-zirconium hydrides or vice versa, 2) impurity effect of hydrogen atoms, or so called as 'high temperature Bordoni peak'. The deviation of resonance frequency to temperature (dfr/dT) shows a minima at a certain temperature and this fact could be corresponded to the terminal solid solubility for dissolution(TSSD) of hydrogen. In order to determine the anistropic elastic constants, initial estimated elastic stiffness was calculated using its orientation distribution function by x-ray diffraction and the reported elastic stiffness of a zirconium single crystal. A nine elastic stiffness tensor for the orthorhombic symmetry was determined in the range of room temperature~400°C. Higher elastic constants along the transverse direction compared to those along the axial or radial direction are similar to the case of Young's modulus or shear modulus. A crossing of elastic constants along axial direction and radial direction was observed near 120°C.

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Nondestructive Online Characterization of Steel Sheets by Harmonic Analysis

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Caused by the ever increasing demand for higher productivity and quality as well as minimization of scrap a 100% quality control is advisable in the production of steel sheet to document the steel sheet quality as well as to enable the implementation of an automatic control system. Such a 100% quality control is only feasible if carded out nondestructively and thus being reliable, accurate as well as quick. A convenient measuring principle is the harmonic analysis of eddy current signals. At the Institute for Material Science, University of Hanover, Germany, a highly sophisticated measuring system based on the stated principle was developed and implemented in close cooperation with the Salzgitter AG in their continuous hot-dip galvanizing production line which operates at sheet velocities in the range from 50 to 170 m/min producing galvanized steel sheet with sheet thicknesses in a range from 0.3 mm to 4.5 mm. Based on the experiences gained in a previous ECSC-project regarding large numbers of steel sheet samples taking from a variety of steel qualities 3-dimensional linear regressions with regression qualities of 85% and higher mechanical-technological characteristic values are computed from nondestructively gained harmonic measuring values. Thus, it is possible to determine the mechanical-technological characteristic values tensile strength /?„ and yield strength *Rpo.2* within the highly integrated online measuring system and to feed these values immediately into the production quality management system as well as to visually present them by the measuring system. Moreover, basic investigations show that the harmonic analysis of eddy current signals is also an appropriate and reliable means to determine nondestructively the consolidation index *n* as well as the anisotropy *r*.

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programme no. **A06-1**

Application of MWM™ Eddy Current Technology during Production of Coated Gas Turbine Components

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Gas turbines blades and vanes in state-of-the art industrial gas turbines have to withstand severe conditions such as high temperatures, corrosive environments and high mechanical stresses – cyclic stresses during start and stop of the turbine as well as static stresses under working conditions – for several 10000 hours. Corrosion and thermal protection coatings are required in order to do so. Deviations in the specified coating thickness tend to reduce the life time of such coatings significantly.
Therefore, the use of a suitable device for thickness control during coating is highly beneficial to ensure the quality of such coatings. In this paper, we present results on coating measurements of metallic MCrAlY coatings on gas turbine parts by means of a "Meandering Winding Magnetometer® (MWM)" eddy current array imaging technology with inductive and magnetoresistive sensors. This technique does also lead to proper coating measurements even after a diffusion heat treatment for a better coating adhesive strength, although the coating and base metal have very similar conductivity values. New capabilities for inspecting gas turbine components are provided. The MWM technology enables to measure the coating thickness and the absolute electrical conductivity, which can be captured features of interest for a population of components, failure evaluations and correlating failure origins to features of specific fleet population segments. Inspection applications include metallic and nonmetallic coating thickness, porosity measurements and detection of cracks on complex surfaces.

Results on coating assessment for a production line of gas turbine vanes by means of a multi frequency MWM™ technique will be presented. Additionally, data on various combinations of coating and base metals will be given.

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STRUCTURE CHARACTERIZATION BY EDDY CURRENT METHOD

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The application of eddy current in non destructive testing was very developed during the last years. From the characterization of defect, currents studies deal with the material metallurgy evaluation. The sensitivity to defects and other parameters of control can be improved by the optimal choice of the probe.

The eddy current imaging method is powerful way to characterize defect types and obtain information from which defect size can be estimated.

A software has been elaborated ,allowing to automate this control and to reconstitute images having two and three dimensions of the controlled samples.

The realized experimentation's have shown large possibilities of analysis by the Eddy current method, the evolution of the various metallurgic characteristics.

The testing data and conditions are directly provided to the software .The results appear under the from of a color or relief graphical chart representing the variation with three dimensions for each one of chosen parameters .

In this paper we study the material structure using eddy current technique ,to characterize the region submitted to thermal processing .Sample of steel have been heated at the temperature 1100 °C with variable maintain time. These methods permits to see the influence of the degree of cold deformation on grain size ,microstructure types ,micro structural changes, hardness changes after thermal treatment.

The objective of this work is to be able to determine the metallurgic features has a steel weakly alloy of nuance 20NC6 having sudden a thermal treätment of homogenization and to characterize by the classic methods as the metallugraphy micro-hardness, toughness and by non destructive methods.

The global different structure analysis revealed that the dependence of the grain size with the temperature follows .The new structure affected the permeability and conductivity and then the impedance.

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Determination of small Electric Conductivity variation by eddy currents.

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The determination of the electric conductivity of a material by eddy currents method's is based on the measure of the variation of impedance of a probe which depends on many factors like the frequency, the magnetic permeability, the lift-off or any other anomaly in the structure.

A physical approach is developed to measure the electric conductivity of the material by employing the diagram of impedance and the various parameters (frequency, factor K....).
The success of this measurement depends on the knowledge of the displacement of all parameters (frequency, electric conductivity, magnetic permeability, lift-off ..) in the diagram of impedance to deduce electric conductivity.

In this objective our work is to develop this physical approach and a simulation for determine electric conductivity variation by eddy currents method's.

The result obtained applied to various specimens like steel, aluminium... are very interesting and with certain conditions we think that it is possible applied this approach in the characterisation of the material in the microelectronic domain.

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Optimisation a digital methods processing of pulsed eddy current

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The application of pulsed eddy current in non destructive testing was very developed during the last years. A broad frequency spectrum is produced in an impulse, the transition signal contains the information of depth of the material. Physically, the impulse is widened and delayed while it travels in the material. Consequently, the anomalies close to surface will earlier affect the response of eddy current.
The modes of presentation of PEC data are analogous to ultrasonic methods in the form of A-, B- and C-scans. The signal treatment can give information about the result interpretation.
The objective of this work is the development of digital methods processing which are to facilitate the characterization of material.
For that we go elaborate a numerical approach allowing to treat signal(PEC) with the various algorithms.
This work will be bracket on the nonferrous material coatings.
The results obtained will make it possible to optimize the use of the pulsed eddy currents in the characterization of materials.

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Interactions of Lateral Electromagnetic Waves at Microwave Frequencies with Metallic Surfaces

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Electromagnetic wave techniques have been used extensively for materials characterization. Microwaves have been used for the measurement of degree of cure in composite materials, eddy current methods have been used for the detection of surface breaking cracks in metal alloys and radio waves have been used as a probe of the earth's crust. For techniques that use propagating waves, there are actually three modes for electromagnetic wave transmission from the source to the receiver: direct waves, reflected waves and lateral waves (also known as surface waves). An interesting characteristic of lateral waves is that they propagate along the boundary between two different materials with the interaction being confined to the boundary region. In this work, the use of lateral waves for remote and noncontacting sensing is considered with an emphasis on characterization of metallic surfaces. The interaction of these waves with near surface microstructural features such as cracks, voids and inclusions is considered showing that lateral waves can be used to detect these features using microwave-based techniques. While the lateral field strength is small compared to other modes, it is shown that this field is sufficiently large to be useful for crack detection purposes. Experiments on stainless steel plates with slit type defects show model system results for the detection of surface breaking defects using this lateral wave method.

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Absolute Electrical Property Imaging Using High Resolution Inductive, Magnetoresistive and Capacitive Sensor Arrays for Materials Characterization

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Recent advances with shaped magnetic and electric field sensor arrays provide new capabilities for absolute imaging of electrical conductivity, magnetic permeability and dielectric permittivity. Arrays of inductive or magnetoresistive sensing elements are used with magnetic field drives while arrays of capacitive sensing elements are used with electric field drives. Specific inspection examples include magnetic permeability measurements of applied and residual stress in steels, magnetic permeability measurement of precrack fatigue damage (due to formation of martensite deformation) in austenitic stainless steels, electrical conductivity measurements in a furnace for heat treatment quality control, multiple frequency electrical conductivity measurements for coating age degradation characterization, imaging of hidden damage (e.g. fatigue and corrosion), and complex permittivity monitoring for curing of epoxies and adhesives. This paper reviews shaped field magnetometer and dielectrometer measurement methods and provides a description of inversion methods for property estimation using physical models.

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CHARACTERISTIQUE DETERMINATION OF XC 48 TREATED THERMALLY BY BARKHAUSEN NOISE

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Controlling of some industrial components require the development of new and particular non destructive testing techniques. To characterise a steel, it would be necessary to know its chemical composition, physico-chemical constitution, metallurgical state (annealed, hammered) and other parameters (superficial and chemical processing, ...). The microstructure of metallic alloy depends on the chemical composition, elaboration processing, and thermal processing.

The testing method using Barkhausen noise (B.N.) is a particular method ,which can be applied on ferromagnetic materials .It is a magnetic non destructive evaluation (NDE) method and can provide very important information about the material structure .

The aim of our work is to study the material structure using these techniques ,to characterize the region submitted to thermal processing .Sample of steel have been heated at the temperature 1100 °C with variable maintain time. These methods permits to see the influence of the degree of cold deformation on grain size ,microstructure types ,micro structural changes, hardness changes after thermal treatment.

The welding causes enormously problems to physicists, by the creation of assigned affected thermally zone (ZAT).This zone is fragile, characterized by a new structuring, that depends on operative conditions to the preliminary, following the gradient of temperature assigned.

The evaluation of the welds is extremely important for the performance of materials, hence the quality and integrity of these joints must be controlled, to ensure that no problem exist in weld The spectral density gotten from the Barkhausen noise and the hardness follows the same evolution ,it would also permit to determine the mechanical characteristic without resorting to the destructive means.

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Dynamic Magnetostriction for Material Characterisation of Micro Structure States of Degraded Structural Steel

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By using EMATs magnetostrictively excited and received ultrasonic waves are strongly affected by the local magnetostriction beneath the transducer area due to magnetoelastic interaction. When the EMAT (electromagnetic acoustical transducer) premagnetization is altered in a magnetic hysteresis cycle the emitted ultrasonic wave amplitude – as function of the hysteresis – shows a characteristic behaviour named as the dynamic magnetostriction. The technique can be applied to non-destructive tests by scanning a component's surface. Like magnetostriction the technique beside microstructure analyses is especially sensitive for load-induced and residual stresses and is developed at the Fraunhofer Institute for NDT, Saarbrücken, to characterise material [1].
The proposed contribution is to research results obtained by characterising a 15NiCuMoNb5 copper content ferritic structural steel which is in use in fossil and nuclear power plants for pressure vessels and steam piping exposed at elevated temperatures. Due to coherent copper precipitates with the diameter in the nm range the material degrades documented by change in hardness, strength and toughness. Dynamic magnetostriction measurements have been performed to follow the dynamics of Cu precipitation and different inspection quantities have been derived from the characteristic curves. These can be applied to micromagnetically characterise the material in terms of degradation.

[1] Dobmann, G.: Residual stress measurement of components by NDT. Journal of Non-Destructive Evaluation 21 (2001), Nr.1, S.29-37, ISSN 0971-0604

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MICROMAGNETIC NDE TECHNIQUES FOR THE CHARACTERIZATION OF PRECIPITATION-INDUCED EMBRITTLEMENT OF 15 NiCuMoNb 5 (WB 36) STEEL

Iris Altpeter, Gerd Dobmann, Klaus Szielasko

The low-alloy, heat-resistant steel 15 NiCuMoNb 5 (WB 36, material number 1.6368) is used as piping and vessel material in boiling water reactor (BWR) and pressurized water reactor (PWR) nuclear power plants in Germany. After long-term service exposure at temperatures above 320 °C, damage was observed during operation (and in one case during in-service hydro-testing). Preliminary investigations concluded that the service-induced hardening and decrease in toughness in WB 36 materials was caused by the precipitation of copper.

For the non-destructive characterization of the precipitation-induced embrittlement of WB 36, service exposure was simulated on a set of tensile test samples. The material was observed to exhibit a peak-hardness of about 240 HV10 after about 1000 hours of service-exposure at 400°C. This is an increase of 40 HV10 with reference to the initial hardness of 200 HV10. As conventional hardness measurements are not applicable in this case, early-detecting the hardness increase non-destructively could enable the provider to stop any further service exposure of the material in time.

Therefore, the suitability of micromagnetic NDE techniques for the non-destructive characterization of the Vickers hardness was investigated. A measurement system was successfully calibrated for the prediction of HV10 by Barkhausen noise and field upper harmonics analysis. The practical applicability of this approach was shown by proving its independence on side-effects like plastic deformation and superimposed tensile loads. In all cases, high correlation ($0.90 < r^2 < 0.99$) and low deviation (10 HV10 < error bandwidth < 5 HV10) between prediction and aim were achieved.

Dynamic magnetostriction measurements and eddy current impedance analyses were found to offer additional possibilities for the non-destructive detection of the hardness changes, as both of them reflect changes in the material's conductivity and permeability.

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programme no. **A07-4**

Barkhausen noise investigation of stress-dependent magnetic properties changes around interacting defects geometries in mild steel

Catalin Mandache*, Lynann Clapham

Magnetic nondestructive testing methods of ferromagnetic materials rely on the knowledge of the sample's local electromagnetic properties. Taking into account that the magnetic properties are nonlinear, hysteretic, and anisotropic, this kind of investigation is difficult and complex.

Defect sizing through magnetic flux leakage (MFL) testing of oil and gas pipelines represents a good example of these difficulties. The stress state (applied, residual, and local - developed around defects) of the pipe wall and its effect on magnetic properties of the steel is very intricate and creates problems in converting the MFL defect signal to actual defect geometry. A particularly challenging situation is that of interacting defects (two pits placed in the vicinity of each other at a distance between their centers equal to less than twice their effective diameter.) Defects act as stress raisers in steel samples, and their mechanical interaction generates regions of stress concentrations in the area between them. These are considerably affecting the macroscopic and microscopic magnetic properties of the steel and consequently, the flow path of magnetic flux lines through the test piece.

Another technique, magnetic Barkhausen noise (MBN), seems to provide reliable detection of both microscopic and macroscopic characteristic of ferromagnetic specimens. This method consists in applying a low frequency magnetic field to the ferromagnetic testing piece and scanning its response by a high-resolution magnetic sensor. The voltage train detected depends on the local irreversible changes in magnetization. These occur as a result of domain wall motion, usually by unpinning of domains from their pinning sites (local energy barriers due to inclusions, voids, and grain boundaries.) Domain walls are impeded in their motion under applied field by regions of inhomogeneous strain, as developed around defects. We experimentally investigate several interacting defects geometries configurations under different stress conditions. The stress concentrations detected in the neighborhood and in the area between the interacting defects quantitatively explain magnetic properties changes under stress and help in MFL tools calibration.

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In-Situ NMR Study of Dynamical Behavior of Point and Line Defects during Deformation of Materials

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Nuclear magnetic resonance pulse techniques were used to characterize the dynamical behavior of vacancies (atomic motion / diffusion) and dislocations (jump distances) during deformation of pure and doped alkali halide single crystals (NaCl and NaF) and thin-foils of Al. Spin-lattice relaxation times in rotating frame ($T_{1\rho}$) enabled an evaluation of the dislocation jump distances in NaCl during constant strain-rate deformation and creep at temperatures below about 500K, while atomic motion dominated at higher temperatures. Deformation induced excess vacancies resulted in enhanced diffusion. CUT-sequence pulse technique allowed an evaluation of the strain-induced vacancy concentration as a function of the strain-rate, strain and temperature in NaCl, NaF and Al. Experimental results correlated with models based on vacancy production through mechanical work (versus thermal jogs) while in-situ annealing of excess vacancies is noted at high temperatures. The investigations clearly reveal the utility of NMR in non-evasively characterizing defect-dynamics in materials during deformation.

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USE OF ULTRASONIC EXCITATION FOR SPECKLE INTERFEROMETRY DEFORMATION- MEASUREMENTS

H. Gerhard, G. Busse

Quality control requires the detection of defects that are caused by the production process or later by deterioration. If such defects are detected early enough the production process can be improved or unsafe components can be exchanged to avoid failure. Often it is necessary to detect the defects in a remote and fast way.

Electronic-speckle-pattern-interferometry (ESPI) determines the difference between two different deformations. The results are fringe patterns, that show contour lines with the same level of deformation. The distance of two fringes is equivalent to half the wavelength of the laser used for ESPI. The components of the object deformations, perpendicular ("out of plane") or tangential ("in-plane") to the object surface can be imaged this way. Therefore a complete 3D-description of the deformation is possible.

This measuring system allows for remote and sensitive detection of hidden defects. The difficulty is to excite the discontinuities of the object by thermal and mechanical methods. By generation of under- and overpressure the defects (e.g. delaminations or cavities) can be located. Heating the object allows to observe cracks.

The drawback of this techniques is that the complete object is deformed. A high order of fringes and a worse resolution are the result. Therefore it is difficult to detect local defects. With ultrasonic excitation the energy of the acoustic wave is converted more efficiently into heat. As hysteresis loop results in heat generation mainly the defect area is heated (1). The entire object has no larger deformation. Therefore ultrasonic excitation is suited for high resolution measurements on defects. Impacts in CFRP-plates and delaminations of wood (with veneer or polymer coating) could be detected and selectively imaged. In addition defects in structures could be located e.g. a stringer delamination of a landing flap. The results were compared to images obtained with other non destructive testing methods (ultrasonic thermography and non linear vibrometry).

(1) Salerno, A.: Ultrasonic Loss Angle with Speckle Interferometry. 5th International Congress on Sound and Vibration, Adelaide, 1997

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Multiple Beam Interferometry and Super-Resolution

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Interferometry is a very powerful non-destructive probe since interferometers resolve dimensions well below the diffraction limits of imaging systems. The recent surge of nano-technology has enormously expanded its applications. Any well-equipped technical facility has an interferometer. Virtually all of these are two-beam types: a laser beam is split into two paths: one for reference; the other is modified by a test object. Combining the beams reveals information about the object. This configuration is simple yet extremely sensitive. A much more sensitive interferometer involves the interference of multiple beams. A multiple beam interferometer (MBI) comprises two partially reflecting surfaces. Light is reflected many times between the surfaces, each with a phase and amplitude change. This sum of many wavefronts is much more sensitive than two-beam interference. Interestingly, transmission lines, Anti-reflection coatings, resonant cavities are MBIs, though not generally perceived as such. Thus, high resonator Qs imply high MBI resolution. We illustrate this connection with two of our projects: 1) non-destructively measuring physical properties of thin films using high Q microwave acoustic resonators. 2) applying MBIs to producing light probes much smaller than Fraunhofer diffraction limits. This technique does not violate Fraunhofer diffraction that predicts beam widths by integrating only a single wavefront across entrance apertures. MBI, by contrast, substantially reduces beam widths by integrating many wavefronts, with systematically varying phases and amplitudes. Beam narrowing using multiple wavefronts, in fact, is a standard practice. Phased array antennas, diffraction gratings, and stellar interferometers all achieve resolution beyond Fraunhofer limits. We describe our two projects including theory, procedures and results.

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Laser Pumped Fluorescence for Detection of Thermal Damage

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Materials such as graphite fiber reinforced epoxy matrix composites may exhibit significant strength loss when exposed to temperatures at or above their cure temperature for extended periods of time. The presence of this degradation is not easily detected using conventional NDE methods such as radiography and ultrasonics. This paper describes the use of Laser Pumped Fluorescence (LPF) methods for detecting and quantifying such damage. The (LPF) approach involves the characterization of the fluorescence spectrum produced in epoxy resin when it is exposed to laser light. This study correlates the intensity and spectral characteristics of this fluorescence with thermal exposure for neat resin and composite specimens (IM7-977 and AS4/3501-6) as well as coupons having epoxy-based coatings.

Measurements were made using a point probe device employing a fiber optic bundle that conveys laser light to the specimen surface using the central fiber in the bundle. The other fibers collect the resulting fluorescence and deliver it to a spectrometer for analysis. This device interrogates a region approximately 0.2 mm in diameter. A low pass filter placed at the entrance to the spectrometer slit blocks the exciting laser light that would normally saturate the spectrometer detectors.

In these studies all of the observed spectra were broadband with most of them resembling a chi-square distribution curve having an extended tail at long wavelengths. The trailing edge of this curve shifts with the level thermal exposure and the intensity of the fluorescence also varies. In neat resin the shift goes monotonically toward longer wavelengths with increasing exposure but the intensity variation is not single valued. In composite results, neither parameter is single valued; however, it is possible to quantify thermal exposure using scatter plot methods that analyze both parameters.

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Non-destructive inspection and Safety Evaluation of Inside Crack by ESPI

Koung Suk Kim

Electronic Speckle Pattern Interferometry (ESPI) for non-contact, non-destructive inspection and safety evaluation is described. Shearography is used widely for non-destructive inspection because of high sensitivity and simple interferometer. The method provides only 2 dimensional geometries of crack and cannot measures crack depth. But, crack depth has influence on safety evaluation. Also, it is difficult to determine the defect size quantitatively because there are so many factors- shearing distance, load, depth of crack, material property and etc.
In this paper inside cracks in pressure pipe are inspected with ESPI and 3D-deformation of object surface around inside crack can be measured and analyzed to strain or stress through the simple processing. The strain distribution related to strain concentration implies information of crack size and shape. So, this paper presents the possibility of quantitative analysis of inside crack more easily using ESPI. Artificial inside crack in pressure pipe is tested and the crack size by ESPI is compared with that of Shearography. Also, the calculated strain/stress is compared with allowable stress, which is based on safety evaluation.

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Fundamentals and Applications of Optical Interferometry as Quantum NDT tools for Monitoring and Measuring Electrochemical Properties of Metals in Aqueous Solutions

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It is well known that electronics instrumentation, i.e. Ammeter, Potential-meter, have been used for years to measure electrochemical properties of metallic electrodes in aqueous solutions. One of the disadvantages of using electronic instruments for the measurement of electrochemical properties is the invasive nature of those instruments to the electrochemical systems of the metallic electrodes in aqueous solutions. In recent work published by the author (1-25) , it has been shown that laser optical interferometry can be used as an optical transducer to characterized the electromagnetic field which develops as a result of the electron conduction in metallic electrodes in aqueous solutions due to the oxidation reaction, corrosion processes, between the electrodes and the aqueous solutions. The characterization of such electromagnetic field and mathematical correlation's of the electromagnetic field to any electrochemical properties, i.e., corrosion current density, electrical resistance, double layer capacitance and so on, would lead to the measurement of the electrochemical properties by a non-invasive method. This is the advantage of using optical interferometry, as quantum NDT tools, to measure the electrochemical properties of metallic electrodes in aqueous solutions as compared to the classical methods. the electronics methods.

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THE IMPORTANCE OF IMAGING IN NONDESTRUCTIVE CHARACTERIZATION OF MATERIALS

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There is an ancient saying that "A picture is worth a thousand words." Never is this more true than when applied to nondestructive characterization of materials. It is also true that it was the very first nondestructive test. After God created the universe, he stopped and "saw that it was good". It may be difficult for modern research scientists and engineers to believe, but visual inspection is still the nondestructive testing technique most often used in practical applications today. In this presentation, examples will be given showing the vast spectrum of applications where imaging dominates and where challenges exist for researchers to develop improved methods. First examples will be given of practical visual inspection as used for nondestructive examination of civil structures. Next, an overview will be given of more advanced imaging methods ranging from schlieren imaging of ultrasonic waves in transparent solids, through ultrasonic C-scans and acoustic microscopy of optically opaque materials. Illustrations will be given of developments in high resolution optical holographic interferometry; infrared and thermal wave imaging, and vibrothermometry. Neutron and x-ray radiographic, tomographic and topographic images will be shown as displayed in real-time on image intensifiers connected to television monitors and/or computer terminals. Finally a challenge will be made to researchers to portray more results from nondestructive characterization of materials in an easily understood visual format, since it will enable less well educated practical nondestructive inspectors to do a better job and make the world safer for all of us and our families.

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ACOUSTIC IMAGING FOR MATERIALS CHARACTERIZATION

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Ultrasonic scanning and array imaging of the subsurface materials features is commonly used for nondestructive evaluation (NDE) and nondestructive materials characterization (NDC). Formation and interpretation of the ultrasonic scan images is often complex and hidden process involving signal processing and wave propagation issues. The signal propagation time and acoustical signal loss are utilized to develop acoustical image maps of a material. In modern composites and in multi-layer complex structures, the image presentation and data interpretation is dependent on proper acoustical signal analysis and processing. Frequency dependent attenuation and sound path distortion due to material in-homogeneity directly influence imaging process. Furthermore, different scanning transducer types render different acoustical information and imaging fidelity (1,2). This paper reviews historical development of acoustical imaging such as C-scan and evolution of conventional immersion and contact ultrasonic imaging methods.

Application of ultrasound to in process or in-situ measurements requires development of new sensors and measurement technology that cannot be meet using traditional ultrasonic devices. Laser ultrasonic and gas coupled ultrasonic trunsduction enables imaging in the environments that cannot support conventional coupled transducers. These new ultrasonic methods have been demonstrated to be very effective tool in characterization of composite materials and structures.

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NDE of Thermal Barrier Coatings

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Coatings are used in the aerospace industry to protect critical components from wear, erosion, corrosion or high temperature oxidation. The use of thermal-barrier coatings in hot-section components of turbine engines requires NDE to assess the uniformity of the coating thickness and porosity content as well as to detect manufacturing flaws and service-induced damage or degradation. The aim of this investigation is to establish the applicability of NDE techniques for evaluating TBC coatings used in critical engine components. NDE methods considered include conventional and leaky wave ultrasonics, eddy current and pulsed eddy current methods as well as x-radiography, thermal imaging and capacitance measurements.

This paper provides a brief review of challenges in NDE of thermal barrier coatings and presents preliminary results of the work carried out on plasma-sprayed TBC specimens. Variations in coating thickness and porosity content are measured using either a combination of eddy current and ultrasonic methods or a combination of eddy current and capacitance measurements. Also, degradation of bond-coat is evaluated using eddy current and pulsed eddy current methods and confirmed by ultrasonic measurements and microscopic examinations.

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Nondestructive Characterization of Lattice Block Material™

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Lattice Block Material™, or LBM™, is a unique lightweight structure consisting of repeated cells with an internal node connected to 10 ligaments (on average) that form a truss-like structure with a high strength-to-weight ratio. Lattice Block Material™ can be manufactured by various methods using a range of materials including metals, alloys and polymers, with the ultimate structure taking on many different forms. In the current investigation, a cast stainless steel (CF-3M) LBM™ structure was fabricated for shipboard applications.

Being a novel structure, unique in design and innovative core building elements (the LBM™) there were no existing guidelines on how to inspect the LBM™ assembly. Furthermore, differences in product design, materials selection and manufacturing process can lead to uncertainty as to the overall performance of a given end product, and this is particularly true during the early design phases of developing a prototype. For this reason a variety of methods were utilized to characterize the cast stainless steel LBM™ structure, including, mechanical testing, metallography, chemical analysis, finite element analysis, and nondestructive evaluation. This paper focuses on the nondestructive methods of characterization, specifically visual inspection, x-ray radiography, x-ray computed tomography and sonic infrared thermography have all been found to be effective means for performing quality assurance checks of the LBM™ structure.

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X-RAY COMPUTED TOMOGRAPHY FOR SOLID ROCKET MOTORS

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In 1995, the U.S. Air Force ICBM System Program Office (SPO) opened its new Computed Tomography (CT) facility employing the ARACOR ICT 2500 CT system, to enhance the SPO's Nondestructive Inspection (NDI) capabilities. The system was characterized by using various material and resolution phantoms. Determining how the CT system responds to each material in the solid rocket motor is critical. Equally important, is understanding how flaws in each material are manifested in the CT data. Solid rocket motor inspection procedures were developed using critical flaw size in each section of the motor. Initially the system was used for flaw detection only. Today CT inspection has been integrated into our solid rocket motor Aging and Surveillance program because it provides quantitative measurements of material characteristics in terms of density and dimension. CT is able to detect subtle changes in material properties and growth of flaws over time to identify any adverse aging trends. This requires baseline CT data on each rocket motor, precise material characterization, and CT system repeatability. An automated analysis is performed using the Automated NDE Data Analysis System (ANDES). ANDES detects flaws in the various solid rocket motor materials by using density (CT number) threshold values. While the CT analysts excel in pattern recognition and feature interpretation, computers excel in measurement and record keeping. ANDES complements human analysis and provides quantitative nondestructive information, allowing informed engineering decisions. Analytical tools and techniques available to the CT technicians include color mapping, contrast variation, and variation in CT number limits. Before and after each rocket motor inspection, system performance is measured by performing a CT scan of an Aluminum disk per ASTM 1695 specification. This data is used to derive Modulation Transfer Function (MTF), Contrast Discrimination Function (CDF), and Contrast-Detail-Dose (CDD) curves from the image. MTF, CDF, and CDD measurements are used to determine total system performance; defect phantoms are used to ensure CT technician's analysis meets standards.

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COMPARING THERMOGRAPHY AND X-RAY COMPUTED TOMOGRAPHY ANALYSES OF COMPOSITE BALLISTIC HELMETS

William H. Green, Nevin L. Rupert, and Charles G. Pergantis

The coupling of x-ray computed tomography (XCT) established baselines with thermographic evaluation could result in a system of inspection for defective personnel protection components at the depot level by technicians with moderate training. XCT inspection was used to determine and define damage baselines within components. These baseline components were scanned using thermography to establish corresponding thermal images. The baseline components were ballistically tested to determine performance as effected by damage level. A limited catalog of thermal patterns was compiled relating the thermal pattern to components suitability for use. At the depot level thermography units could scan personnel protection components and the resulting thermal images compared with cataloged thermal images to insure components viability. This will result in lower life cycle cost and higher effectiveness of personnel protection components. This paper addresses a cursory study into the feasibility of such an approach.

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Non-Destructive Prediction of Material Properties of Steel and Al-Alloys - State and Challenge

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The challenge for future nondestructive techniques is characterized by the two major demands of the users of ND techniques. One is the detectability of defects getting smaller and smaller, is the earlier detection of damages and the reliable characterization of states or evaluation of quantities describing the quality of the component. The second demand is the application of the n.d. techniques as early as possible in the manufacturing process in order to predict the properties of the final product and to enable the optimization of the process. This second demand and the applicability of electromagnetic and ultrasonic techniques will be addressed by the contribution.

The application of multiple parametric regression algorithms yields values for yield and ultimate strength which are within ± 3% in agreement with those, evaluated destructively. Since the established destructive techniques come up to a ± 1% accuracy, the demand towards improvements of the ND techniques is obvious. The quality of the results is governed by the quality of the calibration of the electromagnetic quantities using representative samples of the material to be tested.

Promising correlations are also found between combinations of second and third order elastic constants and the yield strength of steel samples. Improvements of the measuring technique are still needed to make this approach applicable. In daily practice the sound velocities together with the thickness and the content of the major alloying elements are taken to predict the yield strength of steel products. Whereas these and other activities result in a sufficiently accurate prediction of the strength of steel and Al-alloys, there is no promising technique to be seen in order to predict the toughness directly.

The only process integrated application of ND techniques to determine material properties are three different electromagnetic techniques to evaluate the yield strength of cold rolled steel sheet and the application of ultrasonic technique to characterize the drawability of the sheet.

The contribution informs upon the worldwide state of the art and discusses the limitations and the benefits of the application of the n.d. techniques. The authors will try to articulate the next steps towards an improvement of the present situation.

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Non-destructive case depth measuring and monitoring

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Non-destructive case depth measuring on induction-hardened components has been reliably conducted by means of computer-assisted evaluation of ultrasonic reverberation levels. Statistical analyses performed both on large sewing-gear units of cranes, excavators and wind-power stations and on automotive components yielded a measurement uncertainty of better than 0,2 mm, provided the probe could be adjusted to the given application as needed. Thus, compared with the tolerances called for, an adequate process capability can be verified. A new magnetic method is presented which, employed to (i) detect local hardness defects on parts having a complex geometry (crankshafts, gear components with widely different diameters) and (ii) monitor the hardness gradient pattern, utilises field-pattern variations in constant-field magnetisation rather than relying on the conventional alternating-field magnetisation. This approach has produced satisfactory performance when used on small automotive components. Typical results are presented and compared to the metallographic outcome and applications where the case depth is determined by means of hardness-pattern characteristics.

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Evaluation of Stresses in Components using Ultrasonic and Electromagnetic Techniques

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Complementary to the established techniques to evaluate stress states, electromagnetic and ultrasonic techniques permit the evaluation of stresses in surface layers and in the bulk of components, respectively. One advantage of these techniques is the possibility of a fast evaluation of stress states, enabling a continuous analysis along traces to get an information about the stress distribution and the stress inhomogeneities. A disadvantage of both techniques is the influence of changes of micro structural states on the measuring quantities. In case of the electromagnetic techniques, calibrations have to be done, using representative samples in tensile test experiments. The quantitative evaluation of stress states using ultrasonic techniques assumes the knowledge of the acousto-elastic constants.

The influence of the micro structural state on the electromagnetic and acousto-elastic quantities has been studied. Depending on e.g. the steel grade, the hardness, the welding parameters, the micro structural state as well as the texture differs. It is found that the texture and micro structural influence on the acousto-elastic constants is not as significant as it was expected. Applying multiple regression algorithms on the electromagnetic quantities, the microstructural states influence can be suppressed.

Results of ultrasonic and/or electromagnetic stress analysis on rolled plates, in and around welds, along the length of rolls and gear shafts and along a part of a pipeline were mapped. Comparisons with the results of an established technique show the reliable application of both techniques.

The presentation describes the experimental results and discusses the applicability of the electromagnetic and ultrasonic technique and the benefits of the measurements over large areas of the component.

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Microscopic characterization of technical magnetic materials by photothermally modulated stray fields

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The photothermally modulated stray-field (PMS) technique uses a modulated laser beam to heat a ferro- or ferrimagnetic sample locally. Temperature dependent material parameters, like the magnetization, result in a small periodic change of the magnetic stray field over the sample surface. This field is detected by a miniaturized magnetic sensor close to the heated spot. By scanning the laser beam and the sensor over the sample, images of the magnetic structures close to the surface are generated.

A typical range of laser modulation frequencies is between 5 Hz and 100 kHz. At higher frequencies, a sensor coil is used as detector for the modulated normal component of the stray field. In contrast to photoinductive imaging, the detection is purely passive. At frequencies below 100 Hz, new miniaturized sensors based on the anisotropic or the giant magnetoresistance effect were employed and turned out to be advantageous in the signal/noise ratio. Such sensors are also capable to detect the tangential stray field components.

The PMS technique has meanwhile been applied to many magnetic materials, like iron alloys, cast iron, metallic glasses, ferrites and thin magnetic films. Images of the magnetic domain structure and its changes under external magnetic fields were obtained.

As the electromagnetic skin depth is usually larger than the thermal diffusion length, thermal depth profiling can be used to probe depth dependent magnetic structures. First examples are shown for polycrystalline nickel.

The lateral resolution is not determined by the sensor dimensions but by the laser spot diameter (down to 1 micron). Therefore, lift-off effects are small in relation to the lateral resolution achieved. The technique can be applied to technical materials without special pre-treatment of the surface. It is possible to measure through thin non-magnetic coatings.

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Ultrasonic inspection of interfacial adhesive bonding in thin metal-metal sheets

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The substances of different physical nature destined for joining two surfaces of any materials together and thus providing adhesive bond joints have formed a separate group of the adhesives. It is known that adhesive microstructure substantially effect mechanical properties of adhesive materials. Nevertheless until now there is no proper conception on the relation between microstructure and physico-mechanical properties of adhesive materials. In industrial area an empirical relation between character of structural microdefects and mechanical properties (strength) of the assembly is often used, but coefficient of correlation between this two groups of parameters, obtained using different approaches and methods, morphological and mechanical, is comparatively low. It is partly caused by the impossibility to conduct both mechanical tests and microstructure evaluation on the same specimen due to destructive character of conventional methods.

Conventional ultrasound inspection allows evaluating physico-mechanical parameters, such as elasticity, density. Pulsed ultrasonic signals at 2.25 to 10 MHz provide resolution about 0.5 – 2.0 mm that enables one to reveal macrodefects but is not sufficient to achieve proper resolution for revealing microdefects However, in the case of joining of thin metal sheets some conditions create a serious problems for conventional ultrasound inspection . The significant difference in acoustic impedance lead to strong sound reflection and intensive resonance oscillations, whereas significant attenuation of sound wave in viscous adhesive materials dramatically reduces the sensitivity of inspection devices.

The goal of this research was to investigate physical mechanisms of the contrast formation in the process of the visualization of microstructure (flaws, inhomogeneities etc.) in bulk and in interface region of adhesive bonding using acoustical imaging and laser ultrasound approaches. To compare efficiency of different advanced methods, we provide series of experiments with using convenient flaw detector, acoustical microscopy, laser excitation and detection of sound, air-coupled transducer. The range of steel and aluminum samples with epoxy-type adhesion bonding from automotive industry with different kind of artificial defects was investigated. The advantages and limitations for each case are discussed. It is shown, that most critical defects of structure, such as cavities and interruptions of adhesive layer are confidently detectable. Acoustic imaging evaluation of adhesion bonding in the form of B- and C-scans are provided as well as quantitative estimation of adhesion quality. Some optimization is proposed for parameters of ultrasound and equipment.

Survey on NDE of non-metallics

Gerd Busse

Non-metallic materials are of technological interest because of their low production costs and resistance against corrosion or their specific strength exceeding often metal properties. This makes them attractive for aerospace and automotive applications. Manufacturers have a strong responsibility for their product. Therefore quality control is an important task including processing, maintenance and service inspection. This way low quality products can be replaced early enough in order to avoid failure while time-consuming and expensive unnecessary replacement of intact components is avoided.

The considerable experience in non-destructive evaluation (NDE) of metals by ultrasonics, x-rays, and eddy-currents since many years is less applicable to non-metals due to lower atomic weight, higher acoustic attenuation and much lower electrical conductivity. On the other hand, these properties can favour other techniques that are well suited for non-metals. Some of these techniques may be combined e.g. ultrasound and vibrometry or thermography. Due to the broad variety of non-metallics and of their defects one needs very often more than just one NDE method for their characterisation. Of particular interest are remote methods which are also applicable under industrial conditions outside the laboratory.

The paper highlights modern NDE-methods like impedance spectroscopy, non-linear scanning-vibrometry, ultrasound-speckle, elastic wave thermography, microwaves, air ultrasonics, the information that they provide, their specific advantages and limitations. The materials involved are glass fibre (GFRP) or carbon fibre reinforced polymer materials (CFRP) and ceramics. Some examples relate also to metals where cracks and hidden corrosion can be detected (maintenance of aging aircraft).

It is a challenge to further develop these techniques, in order to make the new non-metal materials safer and hence more applicable to new fields.

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Review of Nuclear Magnetic Resonance for Nondestructively Characterizing Materials

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Nuclear Magnetic Resonance (NMR) and related radio frequency techniques, such as Nuclear Quadrupole Resonance (NQR) have been used for a number of years for characterizing various materials primarily in the laboratory. However, developments in recent years in both technique and instrumentation have brought about greater possibilities for practical application. For example, single-side NMR systems have been developed for one side access, Squids are being used in some applications, and various imaging approaches continue to be developed. Materials characterization applications which have been reported include: on-line monitoring of advanced composite fabrication processes such as fiber placement; adhesive bonds; heat damage in composites; concrete and wood; corrosion in aluminum alloys; the dynamic behavior of point and line defects in materials during deformation; fatigue damage in thick composites; and explosive detection. This paper will review a variety of recent materials characterization applications, instrumentation developments, and current research, and will provide an overview of future possibilities for this technology.

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Nondestructive characterization of polymers with NMR in one-sided access technique

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Besides the absence of defects and the geometrical properties, the quality controlling characteristics of polymers are based on their microstructure. Up today, there is a considerable demand on methods capable to characterize these properties in a nondestructive manner. Nuclear magnetic resonance (NMR) is known to be a versatile analytical tool, which is highly sensitive to microstructural features of organic matter. Traditionally, NMR equipment is used for off-line polymer analysis in the laboratory. This conventional NMR equipment can be operated only with small samples. In contrast, the one-sided access (OSA) NMR technique does not restrict the maximum sample size and offers the capability for nondestructive applications on large components and even on stationary objects.
In this contribution, the main important application possibilities of OSA NMR for the nondestructive characterization of cross-linked polymers as cured adhesive resins and elastomeres will be shown. Experimental results will be discussed including the determination of density and moisture in porous polymers and the identification of aged material. Further examples are the monitoring of the adhesive curing processes as well as the detection of mixing errors in two-component adhesives and the assignation of adhesive / dehesive reactions in composites filled with nano-sized particles. Additionally, measuring results of standard reference methods, i.e. conventional analytical methods as well as mechanical destructive testing will be compared to the results of OSA NMR measurements.

But also practical limitations of the OSA NMR method will be illustrated, as the restriction in spatial resolution and the partly unsatisfying sensitivity. Furthermore, the problematic application on components containing metallic parts - e.g. an adhesive joint with metallic adherents - will be discussed. Concluding, current developments respectively future developments will be described aiming to overcome these limitations.

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Non-Contact and Non-Destructive Strain Measurement in Composites

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Our research is aimed at developing a method for a non-contact and non-destructive evaluation of polymeric fiber-reinforced composites via the measurement of strain. The method is based on Qudrupole Resonance spectroscopy (QR), a radio frequency method that is related to the more widely known Magnetic Resonance (MR) spectroscopy.

Tiny crystals of a QR active additive are incorporated into the composite at the time of the manufacture. Stresses acting on the composite lead to strains in the composite matrix, which in turn are transferred to the tiny additive crystals that are embedded in the resin matrix. Using a single-sided radio frequency coil the crystals can be interrogated via radio frequency pulses. The additive crystals give rise to a strain dependent QR frequency response.

We have studied the QR responses of fiberglass/epoxy coupons under tensile loads while simultaneously measuring the strain via an extensometer. The QR responses are quite sensitive to strain. Additionally, studies of composite samples with residual strains that result from manufacturing via compression molding show that mismatches of the coefficients of thermal expansion (CTE) of resin, fibers and additive lead to residual strains that are clearly detectable by Quadrupole Resonance. We also have studied the hysteretic behavior of the QR frequency when load cycles are applied.

The QR based strain sensor can be used to assess the structural health of composite structures, even while they are in-service. The QR based strain measurement can be performed anywhere on the structure and at any time during the lifetime of the structure. The measurement is non-intrusive and non-contacting. In contrast to many other strain sensing techniques, no wires or cables need to be attached and no external load needs to be applied.

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A Novel Technique for Pore Structure Characterization without the Use of Any Toxic Material

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Advanced research and development activities have resulted in a number of novel porous products whose performance and efficiency depend strongly on the characteristics of their pore structure. Therefore, pore structure analysis is important, and reliable and safe techniques for accurate pore structure analysis are required. A novel technique capable of measuring pore volume, pore size, pore distribution and liquid permeability of porous materials is described. The technique is called liquid extrusion porosimetry. It uses a wetting liquid that spontaneously fills the pores of the sample and a membrane whose largest pore diameter is smaller than the smallest pore diameter desired to be measured in the sample. The sample is placed on top of the membrane and pressure of an inert gas is increased on the sample to displace the liquid from pores. The pressure of gas and the volume of the displaced liquid are measured. The pore volume and distribution are calculated. Liquid permeability is obtained when the membrane is removed and the volume of displaced liquid due to pressure on excess liquid maintained on the sample is measured. The wide applicability of the test is demonstrated by results obtained with a variety of porous materials including powders, hydrogel, ceramics, coligen and metals. Intrusion porosimetry could measure pore volume and distribution in some of the materials. However, this technique used toxic mercury and could not measure liquid permeability. Liquid extrusion porosimetry did not use any toxic material.

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Nondestructive evaluation of elastic and piezoelectric properties of ferroelectrics using Atomic Force Acoustic Microscope and piezo-mode techniques.

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Thanks to a variety of Atomic Force Microscopy (AFM) techniques it became possible to study different surface properties at a sub-micron and nanometer scale. In this paper we present the results of applications of Atomic Force Acoustic Microscopy (AFAM) and the ultrasonic piezo-mode to piezoelectric materials.

AFAM and ultrasonic piezo-mode are dynamic modes of AFM operation, where the fact that an AFM cantilever can vibrate like an elastic beam is exploited. In the AFAM technique an ultrasonic transducer emits longitudinal waves into the sample from below and causes out-of-plane oscillations of the upper surface. Via the sensor tip the surface movement excites the cantilever vibrations. The forces acting between the tip and the sample change the boundary conditions of the vibrating system. As a result the system is stiffening and it's resonance frequencies shift to higher values. The values of the contact resonance frequencies depend on the contact stiffness which in turn depend on the Young's modulus and the Poisson ratio of the tip and the probed surface, the static force applied to the tip, the tip radius, and the additional attractive forces between the tip and the sample like electrostatic and adhesive forces. The contact stiffness can be evaluated quantitatively allowing to derive the local indentation modulus under certain conditions. Amplitude and phase of the cantilever vibrations depend on the local tip-sample stiffness, and changes are easily detectable at contact resonance frequencies.

In the ultrasonic piezo-mode a sinusoidal voltage is applied to a conductive cantilever while scanning the surface of a piezoelectric material. A localized electric field emanates from the sensor tip that causes, via the inverse piezoelectric effect, local surface oscillations exciting the cantilever vibrations. It will be shown that the changes of the amplitude and phase of the cantilever vibrations are related to the changes in the piezoelectric properties of the surface.

Furthermore, in both contact-resonance techniques amplitude and phase of the cantilever vibrations can be used as imaging quantities. These images of high resolution provide detailed information about local elastic and piezoelectric properties of materials, e.g. in nanocrystalline thin films and coarse-grained PZT ceramics.

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Qualitative new mechanical properties of micro-structured metallic systems

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Different micro-systems have been developed which only have in common that they are fabricated by processes known from semiconductor technology. The knowledge of used materials that has been gathered in mechanical engineering cannot be used very often in micro-systems technology because it often deals with thin structured layers whose properties are rather different from those of bulk material and even of lateral extended thin films.
In this contribution results of bending tests for various metallic stripes and lines sputtered on Si-substrates are presented. The analysis of their deformation structure during bending reveals anomalous plastic-elastic mechanical properties of the metallic systems of micro- and sub-micrometer dimensions. Just from the beginning the mechanical behaviour is characteristic for a quasi-linear elastic chain coupled to a two-dimensional viscous system. When straining the lines perpendicular to their extension no elastic resistance is observed. Only after achieving a critical strain the normal 3D elastic-plastic behaviour re-entries.
The peculiar mechanical behaviour results in strong stress migration. After annealing at 200 °C originally rectangular cross sections of Cu-lines showed a clear doubling peak structure. Such effects are observed also after few cycles of load. Other practical consequences are discussed concerning the reliability of metallic interconnects, the quality of micro-mirror materials as well as a new approach of micro-material tailoring by surface treatment.

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Elastic-stiffness tensor of a single SiC fiber at elevated temperatures

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We determined all independent elastic-stiffness coefficients Cij of a silicon-carbide fiber (0.14mm in diameter) from room temperature to 900K. The fiber consists of an SiC annulus surrounding a carbon core. Thus, we assume transverse isotropy (hexagonal symmetry) and five effective Cij. The determination procedure involves (i) measurement of elastic-stiffness coefficients of a composite composed of isotropic matrix and the embedded fibers, and (ii) micromechanics calculation for deducing the fiber Cij from the composite Cij, matrix Cij, and the fiber volume fraction. For this, we use a Ti-alloy-matrix composite unidirectionally reinforced by the fibers, which also exhibits transverse isotropy.
The electromagnetic-acoustic-resonance technique contactlessly measures the five Cij of the composite and the two Cij of the matrix, owing to the Lorentz-force mechanism. Subsequent micromechanics calculation uses Mori-Tanaka mean-field theory. The result includes anisotropic temperature derivatives of the fiber Cij; much smaller derivatives of the fiber-longitudinal-direction Cij.

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Anisoropic elastic constants of unidirectional porous copper measured with resonance ultrasound spectroscopy

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We investigated the elastic property of a unidirectional porous copper, regarding it as a composite material of a hexagonal elastic symmetry with c-axis parallel to the longitudinal direction of the pores. In general, the existence of pores makes the ultrasonic measurement difficult, because the scattering inevitably occurs and the conventional pulse-echo method is inapplicable except for a few directions. For this, we used the combination of the resonance ultrasound spectroscopy (RUS) and the electromagnetic acoustic resonance (EMAR) methods to determine the elastic constants of the composite materials with high accuracy. It is observed that the elastic constant c33 and Young's modulus E001 decrease linearly with porosity, while c11 and E100 drop drastically. Micromechanics calculations can reproduce and well explain the measurement results.

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Nondestructive Detection and Characterization of Kirkendall Voids in Clad Metals for Micro-batteries Using Ultrasonic Method

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The clad metals, for examples Cu/Ni, which are used for the anode case of micro-batteries are made by means of the roll and diffusion bonding processings. On manufacturing the clad metals, there is a possibility for the small voids caused by the Kirkendall effect to form in the area close to the bonding interface during diffusion bonding process at elevated temperatures. Such the Kirkendall voids are considered to give rise to deterioration in the material properties of battery case. Hence, from the quality control point of view for battery case materials, the effective NDT technique for integrity evaluation of the clad metals, especially for detection and characterization of small voids in the thin clad metals, is greatly demanded now.

In this paper, the ultrasonic method, which employs a high-frequency focused immersion type transducer and some signal processings, has been applied for nondestructive evaluation of thin clad metals. First, the thin clad metal samples with various sizes of voids in the neighbourhood of bonding interface have been prepared for the ultrasonic examination. For these specimens, the reflected wave signals after transmitting across the bonding interface and void area were digitally measured and their characteristics have been analyzed. This paper focused on the discrimination between the two adjacent pulse echoes from the bonding interface and void layer and also on obtaining the void signal with good signal to noise ratio. Subsequently, the microstructure of clad metals was examined by the SEM and EPMA to determine the size and configuration of Kirkendall voids near the bonding interface area. The results of metallographic examinations were compared with ultrasonic testing's ones. Consequently, it was confirmed that the ultrasonic method presented here has been successfully performed for evaluation of the Kirkendall voids in the clad metals.

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Reference Blocks Problem for Type Testing of Penetrant Systems

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One of the main goals of a type testing pocedure is establishing a sensitivity level of a penetrant system. Obviously it should not be dependent on the laboratory equipment wherever it is carried out. We have carried out experimental investigations of type testing procedure to obtain comparative results for different reference blocks, which are used in different laboratories. To obtain quantitative characteristics of indication's visibility an image-processing system was used.

It was found that such results can be considerably different. For example, we used the same penetrant system (penetrant, remover, developer) carrying out the type testing procedure for 3 sets of different reference blocks. All characteristics of the procedure were equal for every reference block. The usage of one reference block resulted in evaluated sensitivity level 3, whereas the usage of another one resulted in lower sensitivity – the level 2. Apparently, that such situation is unacceptable. To avoid such a nonuniquiness of type testing results we propose as follows.

Two proposals should be realised. The first concerns that reference blocks, which are already used in practice by various institutions. It seems reasonable to establish quantitative correlation between the abilities of various test panels used for determination of penetrant system sensitivity by the independent laboratories. This may be initiated and supervised by CEN/TC 138 in a cooperation with the institutions interested in type testing. Technically it will require carrying out a number of measurements with a use of the image-processing system to obtain comparative quantitative characteristics of indication's visibility on different reference blocks.

The second proposal concerns the producers of reference blocks. A producer should determine the comparative results of indications visibility corresponding each new produced reference blocks before offering it to a customer. Certain reference area (for example 5 indications of 2 cm length) could be accepted as an evaluating area to use the image-processing system for any produced reference block. Obviously such results should be obtained under the constant (and always the same) parameters of type testing procedure.

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X-Ray Diffraction and Refraction Topography of light weight materials

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The limited performance of classical nondestructive methods for the characterization of complex light weight materials and especially of composites is due to their heterogeneous and non- isotropic micro structure and their low electric conductivity. Their mechanical and thermal properties depend strongly on the spatial distribution of pore size, crack density and orientation, compound phases like fiber content and orientation, polymer texture, interfaces and interface debonding. Such micro structural parameters can be imaged by Wide Angle X-Ray Diffraction and Refraction Topography techniques as developed during the last decade.

While classical Wide Angle X-Ray Scattering represents only a very small volume of a sample or it is restricted to single crystals, scanning Diffraction Topography combines the analytical selectivity with high resolution imaging of polycrystalline and amorphous materials. Typical applications reveal the precise local fiber orientation of CFRP, the mixing ratio of carbon and SiC in CMC or the polymer chain orientation in injection molding materials. Interesting structure property relations can be determined.

X-Ray Refraction Topography techniques are based on Ultra Small Angle Scattering of relatively large objects undergoing phase related effects like refraction and total reflection at a few minutes of arc as the refractive index X-rays is nearly unity ($1 - 10^{-5}$). At smaller particle size below some hundred nano meters diffraction prevails. Scanning of samples results in imaging of closed and open pore surfaces of ceramics and foams, crack surface density and orientation in plastics and fiber/matrix debonding of polymer and ceramic composites after cyclic loading and hydro thermal aging. In most cases the investigated surface and interface structures correlate to mechanical properties.

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Synchrotron Radiation Refraction Topography

Bernd R. Mueller, Axel Lange, Manfred. P. Hentschel

The employment of synchrotron radiation for Refraction Topography of materials has considerable advantages over standard X-ray sources. The much higher beam intensity and the parallel and monochromatic radiation provide faster measurements and better angular and spatial resolution. X-ray refraction techniques image the inner surface and interface concentration of micro structured materials. This effect of X-ray optics is additional to small angle scattering by diffraction, when the scattering objects reach micro meter dimensions. Although X-ray total reflection is well known from X-ray mirrors it contributes generally only a minor part to the scattering.

We have developed X-ray refraction techniques within the last decade in order to meet the growing demands for improved non-destructive characterization of high performance composites, ceramics and other low density materials. Submicron particles dimensions, the pore size of ceramics, the crack density distribution and single fibre debonding within damaged composites can be measured and visualized by computer generated interface topographs. For this purpose the investigations are being performed now at the new hard X-ray beamline of the Federal Institute for Materials Research and Testing (BAM) at BESSY, Berlin. This BAM*line* provides monochromatic radiation of photon energies from 5 keV to 60 keV from a double multilayer and/or a double crystal monochromator respectively. A separate instrument is dedicated to the further development and application of Synchrotron Radiation Refraction (SRR) Topography.

Different from conventional small angle scattering cameras with collimating slits and pinholes scattering angles down to a few seconds of arc are selected by a single crystal analyzer, similar to a Bonse-Hart diffractometer. 20 µm spatial resolution of the scattering micro structures is achieved by a CCD-camera with a fluorescent converter. First SRR topographs of aircraft composites (carbon fibre reinforced plastics (CFRP), carbon fibre reinforced ceramics (C/C), metal matrix ceramics (MMC) will be reported.

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programme no. **B01-2**

X-Ray Refraction Topography of Impact Damage of CFRP Laminates

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X-ray refraction topography is a new method for nondestructive testing in the field of X-ray methods. The refraction effect is based on the X-ray beam deflection at micro-surfaces of materials with different electron densities. At the interface of fibres in CFRP laminates X-ray waves are deflected similar to visible light in a lens. In this case X-ray refraction essentially is caused by the differences in the index of refraction between the fibres and the surrounding matrix material. Depending on the interface concentration of bonded and debonded fibres in the composite the refraction factor C gives a measure for the specific inner surface density. It is determined by the relative difference between the measured refraction intensity I_R and the absorption level I_A. The knowledge of the amount of inner surfaces in a composite allows to characterise precisely the fibre/matrix-damage state and may help to predict the mechanical behaviour.
We present a series of two-dimensional X-ray refraction topographs of impacted 0°/90°-CFRP laminates. Unlike in ultrasonic testing there is no shadowing effect on the successive layers by delamination echos. The refraction image inspections show that the fibre/matrix-damaged areas increase significantly with increasing impact energies. From the analytical investigation we conclude a refraction value C which is proportional to the absorbed impact energy per layer. Furthermore the X-ray refraction setup is sensitive to separate the orthogonal arranged fibre orientation. The presented X-ray refraction topographs show the selectively damaged composite states of both (0° and 90°) fibre directions and therefore give a more detailed information about the mechanical performance of CFRP laminates.

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programme no. **B01-3**

PRECISE MEASUREMENTS OF FIBRE DIRECTION, TYPE AND CONTENT IN CFRP BY X-RAY ROTATION TOPOGRAPHY

J. V. Schors, A. Lange, M. P. Hentschel

High stiffness CFRP structures like satellite reflectors request high precision fibre orientation and homogeneity in order to prevent their deformation under thermal load. But related non-destructive techniques have not been available up to now. New X-Ray Rotation Topography (XROT) has overcome this technological gap. The scanning method based on Wide Angle X-Ray Scattering (WAXS) measures the mean fibre direction and the orientation distribution function of CFRP laminate or sandwich at $\pm 0.05°$ angular precision and at 1 mm spatial resolution. Orientation parameters and the mass distribution of selected layer directions are imaged by topographs. Fibre bundles of different modulus can be separated. Typical sandwich materials from a European satellite project (FIRST) have been investigated: The mean angular mismatch within each of the six layers is 0.6° per 100 cm^2. While the relative fibre mass of the sandwich (six fibre directions) varies by only 2%, single layer directions show striations at 5 % mass variation due to the manufacturing process by fibre roving deposition.

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Characterization of microstress states in polycrystalline materials

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The evaluation of X-ray or neutron-ray diffraction peaks allows to study stress- and texture states of polycrystalline materials. Texture analysis uses the intensities of the peaks äs a measure of the volume fraction of the contributing crystal orientations. Stress analysis by diffraction methods are based on the effect that Stresses cause shifts of the interferences and these shifts are connected with respective strains.
Because only those crystallites that are favourably oriented with respect to the direction of measurement contribute to a diffraction peak, the detected strain may differ from the macroscopic mean value. To connect the experimental data with the mean stresses of the considered material phase, e.g. using the sin \)/ method, appropriate elastic constants are used to consider the special elastic properties of the involved crystals. The fact that for each direction of measurement another selection of all crystallites contribute to the diffraction peak enables one to get, besides the macroscopic values, much more information about the strain and stress distribution within the material. Of course, different phases can be studied separately. But also the orientation dependent strains and stresses of the crystallites can be evaluated. In texture analysis different methods has been established for a long time to construct the orientation-distribution-function (ODF) from a couple of intensity-polefigures. m recent years a respective method has been developed to derive the orientation dependence of strains and stresses from strain-polefigures of several lattice planes and to obtain the respective stress- and strain-orientation-functions (SOF). The present paper shortly reviews the procedure of SOF-determination and describe examples of its applications on textured and deformed metais. The evaluations deliver the elastic states of the differently oriented crystallites and a detailed description of the elastic and plastic behaviour of the material phases.

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programme no. **B02-1**

Nondestructive Analysis of Liquid Oxides in Contactless Conditions by Synchrotron Radiation and Neutrons

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Structural characterization of condensed matter by synchrotron radiation combined with neutrons data constitutes a powerful investigation tool in material science. In order to investigate refractory liquids at very high temperatures, we have developed a new high temperature analysis chamber for performing combined X-ray absorption and X-ray diffraction measurements by using a laser heating system and aerodynamic levitation. A similar system has been designed for neutrons experiments. These high temperature equipments present several advantages: the container neither physically nor chemically perturbs the sample, heterogeneous nucleation during cooling is suppressed and pollution by the container is removed. This cell can operate under various gas conditions from room temperature up to 3000°C obtained by a sealed 125 W CO_2 laser. Experiments have been performed at LURE (Orsay, France), at ESRF (Grenoble, France and at ISIS (UK). We have studied the local structure around cations in some liquid and solid oxides. We have shown that temperature synchrotron data combined with neutrons results contain valuable structural information on liquid alumina. About 62% of the aluminum sites are 4-fold coordinated, while some 24% of the aluminum sites are 5-fold coordinated. The octahedral aluminum sites found in crystalline αAl_2O_3 occur only at the 2% level in liquid alumina [1]. Application to a wide range of materials are very important, including ceramics, glasses, battery materials such as halides, fluorides, and molten salts, metals and alloys and semiconductor materials.

(1) C. Landron, L. Hennet, T.E. Jenkins, G.N. Greaves, J.P. Coutures and A.K. Soper, Phys. Rev. Lett. - 86-21, (2001) P. 4839-4832

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programme no. **B02-2**

X-Ray Stress Measurement of Materials Having Nonlinear Sin$^2\psi$ Diagram

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The x-ray method of stress measurement can nondestructively measure residual stress in a localized surface layer of crystalline materials. According to the theory of elasticity for isotropic materials in the plane stress state, the $\sin^2\psi$ diagram representing the variation of the peak position p of a diffraction line with $\sin^2\psi$ is linear, where ψ is an angle between the specimen normal and diffraction plane normal. However, textured materials and ψ-split materials have nonlinear $\sin^2\psi$ diagrams. A new theory was proposed which is applicable to anisotropic materials as well as isotropic materials. This theory is based only on the premise that a lattice strain ε, which is proportional to p, varies proportionally to a stress, that is

$$p = p_0 + k_i(\sigma_a + \sigma_0) \tag{1}$$

where p_0 is a peak position of a stress-free specimen, k_i is a constant depending on the angle ψ, and σ_a and σ_0 are applied and residual stresses, respectively. For isotropic materials, the constant k_i is determined theoretically.

Various stresses σ_a were applied to textured drawn and ground ψ-split steel specimens, and the slopes M of straight lines fitted to peak positions in the $\sin^2\psi$ diagrams were determined by the least squares method. These straight lines cross at a point in the $\sin^2\psi$ diagram. The slopes M of both specimens vary linearly with the applied stress σ_a. The stress constant K can be determined experimentally from the slope B of the straight line in the M versus σ_a diagram as $K=1/B$. The constant k_i was determined from the slope of a straight lines of the relationship between the peak positions p for various fixed ψ angles and σ_a. The k_i value for the ψ-split specimen fell on a theoretical straight line, while the value for the textured specimen oscillates with $\sin^2\psi$ similarly to its $\sin^2\psi$ diagram.

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X-Ray Study on Plastic Strain Distribution in Soft Zone of A5052-H Weld Metal

M. Katoh, K. Nishio, T. Yamaguchi

In ship yards, for example, they prefer to use work-hardened aluminum sheets instead of annealed sheets for weld materials of ships because of the easiness of handling them. When we perform fusion welding on the work-hardened aluminum sheets soft zone is developed near weld metal. This zone influences mechanical properties of weld joints. In this study the authors examined plastic strain distribution in the soft zone by applying X-ray diffraction technique. The plastic strain is estimated by integral breadth of X-ray diffraction intensity curve. Since we need some area for irradiating X-rays we study the appropriate irradiation width by simulating the plastic strain distribution by considering the influence of the irradiation width and make clear that the width less than 5mm is enough. The plastic strain has the value of 0% near fusion boundary, increases abruptly into heat-affected-zone and reaches the value of the work-hardened (about 13%). The width of the soft zone depends on weld heat input. The larger the heat input, the wider the width. By examining the temperature distribution during welding, plastic strain tends to decrease when the material is heated higher than about 573K and to be zero percent higher than about 673K. When we perform welding by YAG laser it is possible to decrease the width of soft zone, but not possible to obtain no soft zone.

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NONDESTRUCTIVE EVALUATION AND CHARACTERIZATION OF COMPLEX COMPOSITE STRUCTURES

Gary W. Carriveau, Reza Zoughi

Because of the variety of materials used and the nature of manufacturing processes it is often very difficult to effectively inspect and characterize complex composite structures. While no single NDE technology might be expected to totally provide the necessary information, we have found that microwave NDE can address and answer most inspection and characterization needs. This paper describes a series of tests that have been performed on a variety of thick, complex composite structures. The measurements were performed to assess the efficacy of this method when looking for typical flaws and defects found in this type of material. These include: delaminations between plies, resin rich and resin poor areas, porosity, inclusions, contact and correct filling between laminate and adhesive, thickness of adhesive, correct placement of components and assemblies, impact damage, etc. Special attention was placed on areas where there are significant changes in the types of materials used (transition areas) and variations in the thickness and/or geometry of the structure being inspected. Microwave results will be compared with ultrasonic and x-ray radiography.

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programme no. **B03-1**

Inspection of dielectric materials with microwaves

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Anisotropies in materials may result from production: During the injection moulding process of short fiber reinforced polymers, the fibers align with the mould. The resulting fiber orientation determines the mechanical behaviour of the product.
As the fiber orientation causes dielectric anisotropy whose axis is along the fiber, one can use linearly polarized microwaves for nondestructive and fast probing of fibre orientation: The interaction between the sample and the microwave field shining on it depends on the angle between the fiber and the field. Therefore the rotation of the linearly polarized microwave field with respect to the sample results in a double periodical detector signal from which both the direction and the degree of fiber orientation (or generally: anisotropy) can be calculated by Fourier transformation. The obtained result can be visualized by a line whose direction indicates the fiber orientation while the line length represents the degree of orientation. This way a two dimensional raster scan provides information on fiber orientation fields.

Further applications of microwave measurements are presented:
A sharp increase of microwave anisotropy is found in damaged fiber reinforced plastics. Therefore the nondestructive microwave method allows for continuous monitoring of increasingly damaged samples.

Another microwave technique based on the reflection behaviour of dielectric materials can be used for the detection of inhomogeneities. Annual rings and knotholes in wood are distinguishable with high lateral resolution that way.

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programme no. **B03-2**

CHARACTERIZATION OF LAYERED DIELECTRIC COMPOSITES BY RADAR TECHNIQUES

John M. Liu

The dielectric properties of polymer-based composites change with the temperature and moisture environment. Such changes are of interest for the consideration of the stability and longevity of composite structures. Various radio frequency and microwave techniques are in use for the determination of the dielectric properties, including the use of open-ended wave guides, resonators, and free-space techniques. The unique inversion for the material properties usually requires the collection of data over wide bandwidth, which is burdensome and costly for many NDE applications.

We present in this paper an application of parameters estimation techniques originated from the fields of Radar and acoustics, which relaxes the requirements of wide band electronics and yet provides good results for property determination. Examples will be presented on the changes in the dielectric properties of composites with the environment.

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programme no. **B03-3**

DETECTION OF HIDDEN CORROSION UNDER PAINT

Prof. Dr. J. Otto and Dipl.-Ing. (FH) M. Hald

Corrosion causes tremendous costs in industry. Air planes for example must be free of any defects which could give danger to the lifes of the passengers. Hidden under paint there may already be dangerous corrosion, which up to now can't be detected. Therefore planes have to stripped from paint in regular time intervals to evaluate the metallic surface by optical means. This results in much expenditure of paint, man power, time and environmental costs.

This paper presents a new method for non-destructive detection of corrosion under paint using microwaves. Organic materials, especially paint, is in contrary to visibly light transparent for microwaves. Therefore the metallic surface beneath the paint can be characterized as if there were no paint.

We use a microwave Doppler sensor with a transmit frequency of 94 GHz, whose antenna illuminates the surface under an angle of 45° with a beam divergence of 20°. The sensor is moved parallel to the surface. Because of the reflection law the sensor detects no signal, if the surface is smooth. If the surface contains defects or any kind of roughness, parts of the incident signal will be reflected back to the antenna. Depending on the kind of defects, the radiation will be scattered in different directions and with different amplitudes. Furthermore, because of the movement of the sensor, we get different Doppler frequency shifts of the reflected signal.

The received microwave signal is mixed down to the base band, sampled and transformed to the frequency region. Depending on the kind of surface defects, roughness and the type of corrosion there are different frequency spectra and time-frequency-behaviours. Adaptived algorithms employ different time frequency transformations like short time fourier transform, Wigner-Ville distribution and wavelet analysis. Characteristic patterns of the time signals and/or frequency spectra are used for classification. Using a neural network (multilayer perceptron) classification can be automazed and faulty regions will be detected.

So in future it may be possible by using this sensor to detect hidden corrosion under paint, adapt maintenance intervals of for example air planes to the real need and to characterise surface roughness and surface profiles via non contacting microwaves.

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programme no. **B03-4**

Near-Field Inspection of Thermal Barrier Coating for Thickness, Disbond, Delamination, Corrosion and Porosity

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Thermal barrier coatings (TBC) are critical structural components used in critical aerospace applications. Therefore, keeping the structural integrity of these coatings intact is of utmost importance. Inspection of these TBC may present some challenges to nondestructive testing "toolbox". However, near-field microwave nondestructive testing and evaluation techniques, using open-ended rectangular waveguides and open-ended coaxial probes are well suited for inspection of these coatings. These techniques are capable of evaluating several important anomalies in TBC such as thickness, thickness variation, disbond between the coating and the substrate, delamination in the coating, corrosion under the coating and increase in porosity due to accumulation of micro cracking in the coating. These measurements can be conducted in an in-contact or non-contact manner. When in contact mode, there is no need for using couplant to couple the microwave signal into the coating. Moreover, frequency of operation and standoff distance can be used to enhance measurement sensitivity to the parameters of interest such as thickness variation or disbond detection. In this paper, the capability of these techniques for inspecting the above-mentioned anomalies in TBC will be presented. A discussion of their applicability for on-site evaluation will also be presented.

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programme no. **B03-5**

MICROWAVE NONDESTRUCTIVE EVALUATION AND CHARACTERIZATION OF TANK INNER-LINERS

Gary W. Carriveau
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Reza Zoughi, Dana Hughes and Nasser Qaddoumi*
* while on visit from the American University in Sharjah, UAE.

Tanks containing caustic and hazardous materials are found in many industries. For example, the petro-chemical industry uses tanks for containment of a variety of potentially hazardous liquids, in both mobile (railroad and truck transport) and fixed site installations. Most tanks contain an inner-liner that is intended to protect the exterior structural vessel containing the liquid. If this inner-liner is damaged the caustic/corrosive liquid may attack the exterior tank which can then result in leaks and serious damage. Inner-liners in railroad tank cars intended to transport caustic liquids are typically inspected using a high-voltage "spark" test to check their condition. This method suffers from a number of serious limitations. We have performed a series of experiments using a new approach employing near-field microwave NDE technqiues to measure and determine the integrity of tank inner-liners. It will be shown that this advanced technique can effectively detect and characterize a variety of inner-liner defects including damage such as cuts or breaks, disbonds between the inner-liner and exterior tank, and incursion of liquid between the liner and tank. The method can also be used to determine the efficacy of required repairs. It is important to note that this approach can be used for all types of tank liners as long as they are non-conductive, such as rubber, polymer, plastic, paint, etc.

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programme no. **B04-1**

MAPPING OF POROSITY CLUSTERS IN MARINE COMPOSITES USING MILLIMETER WAVE

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Composites for marine applications typically are several inches thick, with layer architecture. These structures can be tens of feet in dimensions laterally and vertically. Many are made of a polymer-based composite sheet sandwiched between a core of rigid foam or balsa wood. The manufacturing processes used are less elaborate than those used for aerospace structures. Even though through-transmission ultrasound is successful for porosity detection in these composites, the large physical size of the assembled structures makes this ultrasound technique impractical.

We present in this paper a non-contact technique using millimeter wave for the characterization of porosity clusters in composite specimens, using a focussed beam in E band. The measurement system consists of electronics originally designed for automobile collision avoidance purposes. A data collection system is built around a portable spatial location device. We will present maps of porosity clusters and make comparison with visual images obtained before and after surface painting. Improvements in image contrast achieved by the application of image processing techniques will be demonstrated.

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Near-Field Microwave and Embedded Modulated Scattering Techniques for Dielectric Characterization of Material

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Near-field microwave nondestructive testing techniques, using open-ended waveguide probes, have been extensively used for inspection of a wide variety of structures and composites. Modulated scattering techniques, using PIN diode-loaded resonant dipole antennas been used at microwave frequencies for nondestructive testing, antenna pattern measurement, electromagnetic field mapping and radar cross-section measurement applications. In this approach, the PIN diode is forward and reverse biased using a rectangular pulse train. Consequently, the dipole antenna is loaded with a short or a near-open load as a function of time. When a dipole antenna is embedded inside of a dielectric material, its impedance is not only a function of frequency and dipole dimensions, but also a function of the dielectric properties of the medium in which it is embedded. The periodic impedance loading of the PIN diode changes the dipole impedance during the forward and reserve stages of the diode. The diode impedance is not a function of the dielectric properties of the material, however the dipole impedance is. Thus, the forward and reverse reflection properties of the dipole scatterer change as a function of changes in the material dielectric properties. Subsequently, the comparison between the reflection coefficient of the dipole antenna between the forward and reverse cases can be used to evaluate the dielectric properties of the material. This results in a rapid, nondestructive and sensitive dielectric measurement technique. The derivation of the dipole impedance in these two stages will be presented as well as the results of a preliminary measurement for evaluating the dielectric properties of mortar exposed to a chloride solution and a low permittivity thick composite material exposed to water permeation.

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Inversion Procedures for Microwave NDE Applications

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The use of microwave imaging techniques for the detection of cracks and defects located in inaccessible domains is a challenging problem for the NDE community [1]. One of the critical points related to the realization of efficient electromagnetic imaging systems is represented by the development of efficient reconstruction procedures. The main difficulties are related to the non-linear ill-posed inverse scattering problem that must be solved in order to obtain information on the unknown defect starting from field scattered data. The use of genetic algorithms (GAs) has been recently proposed by several authors to sölve electromagnetic inverse problems. In this paper, we propose the application of a GA to tomographic imaging for nondestructive applications. In particular, a hybridized version of the GA is applied. The stochastic minimization is applied to a functional, which is constituted by two terms. The first one is the "data term" and is related to the difference between the measured scattered data and the data predicted by the procedure at any iteration. The second term is related to the so-called "state equation," which imposes that the reconstructed object and the predicted electric field (inside the object) be consistent with the known incident field. Since the internal field is unknown, the problem is a nonlinear minimization problem with a large number of unknowns. Then, in order to increase the convergence velocity, a local search method (a Polak-Ribière conjugate gradient (CG)) is merged into the global optimization loop performed by means of the GA. The hybrid code GA-CG seems to be suitable for this problem. In order to assess the resolution properties of the proposed method, the case of multiple separate dissipative scatterers is analyzed.

[1] D. Hughes and R. Zoughi, "A method for evaluating the dielectric properties of composites using a combined embedded modulated scattering and near-field microwave nondestructive testing technique," Proc. 18*th* IEEE Instrum. Meas. Techol. Conf., Budapest, Hungary, pp. 1882-1886, 2001.

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programme no. **B04-4**

Characterization of surface cracks in metals by microwave techniques

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There is a considerable interest in defect detection, sizing, identifying and classifying preferably through non destructive techniques. Among the methods that have shown very interesting capabilities for this kind of tests we find microwave techniques. So, to respond to this characterization demand a microwave system for the determination of the material under test reflection coefficient (magnitude and phase) at millimeter wave frequencies has been conceived. This system that operates at 35 GHz has been realized in microstrip technology and named SPMS-35000 (S-Parameters Measurement Systems).
We have already shown that this device is well suited for near-field nondestructive applications such as the detection of flaws inside dielectric materials or on surface conductors. In this study we propose to demonstrate how we can retrieve, more accurately, information collected from the measurement of the reflection coefficient of an open ended rectangular waveguide by using signal processing techniques. To that end a blind deconvolution approach is used. The measured data are considered to be the result of a convolution of the real data with a Point Spread Function (PSF) that depends mainly on the operating frequency, the dimensions of the waveguide, the characteristics of the structure under test and the standoff distance between the waveguide and the object. The proposed algorithm is an iterative one, which considers a maximum likelihood estimation.
Several cases are investigated to demonstrate the capabilities of the method. In particular, tests are made for different standoff distances and structures. Flaws covered by a dielectric material are also considered in this study.

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Combined Bi-Static Near-Field Microwave and Modulated Scattering Techniques for Detection of Embedded Targets

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Near-field microwave nondestructive testing techniques, using open-ended waveguide probes, have been extensively used for inspection of a wide variety of structures and composites. Modulated scattering techniques, using PIN diode-loaded resonant dipole antennas been used at microwave frequencies for nondestructive testing, antenna pattern measurement, electromagnetic field mapping and radar cross-section measurement applications. In this approach, the PIN diode is forward and reverse biased using a rectangular pulse train. Consequently, the dipole antenna is loaded with a short or a near-open load as a function of time. Any reflection or scattering from this dipole is then modulated by this periodic impedance loading which makes the scattered field form the dipole distinct from all other scattered fields. In recent years, these two methods have been combined for nondestructive testing applications. Such a dipole antenna embedded inside of a mortar specimen was used to evaluate its permittivity. The combination of these two techniques is expected to overcome some of the weaknesses of the latter techniques by improving signal-to-ratio (S/N) associated with a target and the ability of embedding these dipole antennas inside of composite structures. This paper discusses the preliminary results of using a combination of these two techniques in a bi-static arrangement to detect weakly scattering defects such as delamination in a composite material or periodically appearing hard targets such as reinforcing steel bars in concrete structures. The results of these investigations as well issues associated with optimizing corresponding measurement parameters will be presented.

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Microwave Reflection and Dielectric Properties of Mortar Exposed to Periodic Chloride Solution with 1% Salinity and Compression Force

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Concentrations of aggressive ions, such as chloride ions, near the steel in reinforced concrete can bring about depassivation, leading to corrosion. Corrosion of steel rebar adversely compromises the strength and integrity of affected structures. Although techniques exist for detecting chlorides and monitoring chloride ingress into concrete structures, their drawbacks include that they may be destructive, time consuming and cannot be used for the interrogation of large surfaces. In recent years, several near-field microwave nondestructive testing techniques have been used to evaluate various properties of cement-based materials. It has also been shown that the presence of chloride in mortar specimens periodically exposed to chloride solution can be detected using these techniques. In the present investigation, cubic (8"x 8"x8") mortar specimens were produced with water-to-cement (*w/c*) ratio of 0.5 and sand-to-cement (*s/c*) ratio of 2.5 using Type I/II Portland cement. Since the majority of field exposure to chloride is cyclical in nature, these specimens were cyclically exposed to a chloride bath with a salinity of 1%. To further simulate the service environment and also to promote penetration of chloride in mortar specimen, in the present investigations these specimens are also loaded to 50% of their expected compressive strength before exposure to chloride bath. Daily near-field microwave reflection and dielectric property measurements were conducted on these specimens, at S-band (3 GHz) and X-band (10 GHz), after they were taken out of the chloride bath. Similar measurements were also conducted on an identical specimen which was neither exposed to the chloride solution nor to loading. This paper presents the results of these measurements as well as a complete discussion of the findings.

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Microwave Far-Field Nondestructive Detection and Characterization of Disbonds in Concrete Structures

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Inspection of concrete structures is an important and challenging issue. Standard nondestructive testing methods are not always capable of testing these structures for the presence of disbonds. Near-field microwave nondestructive testing methods have shown great potential for this purpose. Although these methods are very sensitive to the presence of thin disbonds, they are also very sensitive to variations in the standoff distance. Concrete structures are generally large in size and have some surface roughness associated with them. This paper presents a far-field microwave nondestructive testing technique for disband detection and evaluation in a structure made of any number of layers backed by an infinite half space or by a conducting plate. A theoretical model describing the interaction of the waves in the far-field with the layered medium will be presented. The theoretical model calculates the effective reflection coefficient of the structure as a function of the frequency of operation and the thickness and dielectric properties of the layers of the structures. The presence of a disbond in a structure is viewed as an additional layer and will change the properties of the effective reflection coefficient (phase and magnitude). This change will depend on the thickness and location of the disbond. This fact will be used to investigate the potential of utilizing multiple frequency measurements to obtain disbond location and thickness information. The far-field approach will be compared to the near-field approach including the influence of surface roughness. Finally, experimental results will be presented and compared to the theoretical results.

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CHARACTERIZATION OF CEMENT-BASED MATERIALS USING MICROWAVE REFLECTION AND TRANSMISSION MEASUREMENTS

S.N.Kharkovsky, C.D.Atis, U.C.Hazar

Cement-based materials (cement paste, mortar, concrete etc.) are widely used in many structures of the construction industry. Knowledge of physical properties of such construction materials is very important for determination of their quality. For example, one of the most important parameters associated with concrete is its compressive strength, which depend on water-cement ratio (w/c).

Microwave (MW) nondestructive techniques have shown great potential for the determination of the cement-based materials properties. Resent investigations by R.Zoughi *et al* have demonstrated the capability of microwaves to detect the state and degree of chemical reaction (hydration) in cement-based materials.

In this paper results of a measurement and monitoring of cement-based materials properties during long time, including early stage, using reflection and transmission measurements at X-band are presented. Influence of curing conditions on the cubic and rectangular specimens is studied.

First, the propagation factor, reflection and transmission coefficients and insertion loss of the plane wave interacting with the cement-based specimen has been analysed. It is shown that the complex dielectric permittivity of it can be evaluated by measuring of only the amplitudes of reflection and transmission coefficients and using numerical calculation or calibration procedure. Next, a description of the used measurement system is given. Influences of multiple reflections inside the specimen, edge diffraction effects and surface roughness are analysed. Possibilities of a minimization of these influences are shown. Then, new results about dependencies of the amplitude of reflection and transmission coefficients on thickness, surface roughness etc. of the specimens at different frequencies as well as temporal dependencies of amplitude of transmission coefficients for the fresh (1-28 days) specimens are presented.

The combined use of reflection and transmission measurements can be useful for quality control of cement-based structures of the construction industry. Besides, knowledge of reflection and transmission properties of such materials is important in propagation-related research, for example, MW propagation modelling to develop indoors wireless communication systems.

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Microwave Imaging with Atomic Force Microscopy

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In microwave microscopy, objects that are much smaller than the wavelength of the excitation electromagnetic waves are detected and imaged. During the past 12 years different researchers have developed a variety of different techniques and microwave probes to achieve such a "super-resolution" imaging. In some cases, these methods are shown to even achieve atomic resolutions. Owing to their high operation frequencies of 1-140 GHz, these techniques have very high scan rates and they can potentially provide information regarding the identity of the imaged object by not only resolving its features but also by providing detailed information regarding its complex permittivity function at different frequencies. Moreover, the EMP can be incorporated on an atomic force microscope cantilever tip to form a coupled microwave-AFM system to investigate both the topography and microwave characteristics of the sample with nearly atomic resolutions simultaneously. In addition to the obvious applications of the EMP and EMP-AFM probes in electronic industries, device research work, and nondestructive evaluation of materials, they also have interesting applications in emerging fields of nano-technolgy, molecular electronics, and quantum computers.

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Use of 3D micro tomography for the investigation of the mechanical properties of cellular metals

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The advantage of cellular metals lies in the combination of different properties: they are lightweight and strong; they have high acoustic damping and are fire resistant. This makes them attractive for a number of different applications. For industrial purposes the understanding of the mechanical behaviour of the cellular metals is important. 3D micro computed tomography was used for the investigation of cellular metals. Different types of cellular metals were investigated. The purpose of this research was to establish the correlation between structural and mechanical properties. Therefore different software programs were developed, which enable to analyse properties of the cellular metals from 3D tomograms. Using these programs the average density can be calculated, the pore size distribution can be found, walls and nodes can be separated, the shift of the different parts of strength tested foams can be found. Also the correlation between deformation and density was investigated in 3D.

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Characterization of Materials Structure by Dynamic Tomography

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Common tomographic techniques assign a measure of material properties to a discrete element in the object space in order to characterize a component. The discretization, i.e. the volume or size of a single element in the object space, is limited mainly by the physical mechanisms and the equipment used for the data acquisition. In any case the result of reconstruction yields a statistical average within the considered element in the object space. To evaluate the integrity of the component the determined measures have to be correlated with its mechanical properties. Considering modern materials like reinforced plastics or metal foams the mechanical properties of the component are not determined by every single structural element like a single fiber in a composite material. Moreover the ensemble average and correlation properties as a means of statistical measure of all structural elements form the mechanical properties of the component. Accordingly a statistical description of the material properties on a macroscopic scale allow to characterize its mechanical behavior or lifetime. Special reconstruction algorithms are investigated that allow the statistical description of complex object structures including its dynamics. The algorithm is based on a modified Kalman filter using statistical prior. The prior includes knowledge about the covariance matrix as well as prior assumptions about the probability density distribution function. The resulting algorithm is recursive yielding the optimal or quasi-optimal solution at every reconstruction step. The applicability of the developed algorithm is discussed for the investigation of a specimen made from aluminum foam and compared to standard 3D CT.

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INVESTIGATING BALLISTIC IMPACT DAMAGE IN LIGHTWEIGHT CERAMIC ARMOR DESIGNS USING ADVANCED COMPUTED TOMOGRAPHY

William H. Green, Nevin L. Rupert, and Joseph M. Wells

Ballistic impact damage in lightweight, brittle armor ceramics consists of multiple, distributed, and frequently interconnected, cracks of varying sizes ranging from microns to millimeters. Three-dimensional (3-D) postmortem assessment of this type of damage in armor ceramic targets is a highly desirable yet difficult task. However, recent developments with the extensive application of the nondestructive technique of x-ray computed tomography, XCT, have offered a potential solution to this problem. Previously, only select areas of damage have been captured on two-dimensional (2-D) images from cross-sectioned and polished ceramic target samples. In this presentation, the authors give an overview of their research results utilizing XCT techniques to nondestructively reveal the internal meso-scale damage morphology within armor ceramic targets of TiC, TiB_2, Al_2O_3, and SiC. These results demonstrate the innovative and powerful nature of this method in the 2-D and 3-D visualization of internal physical damage. The damage examined occurred in situ either during fabrication of the specimens or by high velocity ballistic impact of these ceramics in confined or encapsulated assemblies. An example of significant pre-impact damage, found in an as-fabricated encapsulated sample, is discussed which makes a case for the baseline XCT examination of encapsulated samples before as well as after impact. Post-impact samples, which are not severely overmatched by the threat, retain sufficient intact ceramic to allow for such damage assessment by XCT characterization.

Examples of in situ physical damage observed include traditional conical, radial and laminar cracking in impacted samples both with and without penetration. Additional observations reveal instances of outer edge radial cracks, periodic through-thickness laminar cracks, and concentric in-plane circular cracking "beachmarks". Examples of asymmetric mixed-type cracking damage isolation point clouds and of the spatial distribution of residual tungsten alloy penetrator material are also presented for improved 3-D visualization of complex internal damage conditions. Visualization of isolated ceramic material corresponding with residual penetrator material in the same observed locations (i.e., surfaces or volumes) is also presented. Finally, the authors discuss the premise that this observed meso-scale cracking contributes significantly to the onset conditions for penetration.

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Reduction of Beam Hardening Artifacts in X-ray Microtomography Data

H.-A. Crostack, J. Nellesen

CT-systems are usually equipped with polyenergetic X-ray sources, X-ray tubes namely, and non-energy dispersive detector systems. Under these experimental limitations the energy dependences of the X-ray attenuation coefficients of the materials are not taken into account during the acquisition of projection data of the scanned object. In the subsequent reconstruction process Beer's law is applied, which only holds in case of monochromatic radiation. Due to these facts errors are introduced into the CT-images, which are summarized as *beam hardening artifact*. Beam hardening results in an apparent gradient of the linear attenuation coefficient in the CT cross section indicating a non-existent density or composition gradient in the scanned object. In the past, a lot of studies were carried out to reduce this image artifact.

In this paper, a beam hardening correction method is presented, which is based on the simulation of the polyenergetic projection data for the object. The method has been tested both for real objects and for phantom objects, which are composed by a superposition of convex geometric primitives like ellipses and polygons in 2D and ellipsoids, cylinders, cones etc. in 3D. In order to verify the projection data of phantom objects, which are described as vector graphics, a digitization method was developed to obtain a pixel, respectively voxel, representation of the object. The knowledge of the source spectrum, the composition of the object and the thicknesses for each material, which can be estimated from uncorrected CT-slices or which are available from technical drawings, are required in the presented approach. With the simulation tool the projection error can be approximated from which an error estimation image for the CT-data is calculated. In this manner the beam hardening artifact in CT-data is minimized iteratively.

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The Use of X-ray Computed Tomography in Quantifying Air Voids in Asphalt Compacted Specimens

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This study describes experimental and analytical methods to quantify the internal structure of air voids in asphalt mixes. An x-ray computed tomography system along with image analysis techniques were used to measure air void sizes at different depths within asphalt mix specimens. The statistical analyses performed validated the applicability of the Weibull model for describing air void distribution. Consequently, the Weibull model was used to quantify the effect of the compaction effort, method of compaction and aggregate size distribution on air voids.

The air void size distribution in Superpave gyratory compacted specimens was found to exhibit a "bath-tub" shape where larger voids were present at the top and bottom parts of a specimen. This shape was more pronounced at higher compaction efforts. The method of compaction was significant in influencing the air void size distribution. Specimens prepared using the Superpave gyratory compactor with different aggregate sizes were found to have noticeably different air void sizes. Specifically, larger air voids were present in specimens that consisted of smaller aggregate particles.

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Thermographic Signal Reconstruction for Enhanced Characterization of Materials

S.M. Shepard, J.R Lhota, D. Wang, T. Ahmed, B. Rubadeux and B. Chaudhry

Common approaches to analysis and enhancement are based on either contrast methods, which require identification or synthesis of a defect free reference region in the field of view, or gated average or slope calculations to enhance signal to noise. The contrast approach is heavily dependent on the location and quality of the reference, while the gated approach has limited value for characterization of defect free samples. In Thermographic Signal Reconstruction (TSR), the entire post-excitation sequence for each pixel is analyzed using a novel method that allows simultaneous noise reduction, defect identification and measurement, material characterization and lossless data compression. The TSR approach does not require the use of a reference region, yet it allows quantitative measurements that surpass contrast-based results. The result of the TSR process is that the time evolution of each pixel, comprising several hundred frames, is expressed as a simple parametric equation. The resulting data compression (typically an order of magnitude) enables analysis of large samples (i.e. sample area greater than camera field of view), through parallel processing of data from multiple sub-regions. Examples of TSR and comparable contrast and gated results on composite and metal samples will be presented.

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Development in Thermosonic NDE Technique

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Abstract. A NDE technique, thermosonics, has been developed at Wayne State University[4,5,6] This technique employs a single, short pulse of sound/ultrasound to cause defects such as cracks to heat up and become visible in the infrared (IR). A low frequency (15 to 40 kHz) ultrasonic transducer fills the sample with sound that causes frictional heating at defect interfaces. Although this new process superficially resembles SPATE (Stress Pattern Analysis by Thermal Emission), SPATE depends on periodic thermoelastic temperature variations, with synchronous detection (at the vibration frequency) of these temperature variations associated with the sinusoidal stress-induced heating and cooling. In contrast, the low frequency thermoelastic heating and cooling variations associated with our sonic pulse are averaged out over the 1 ms (or so) integration time of the IR camera. Thus, only the irreversible temperature increases are imaged by an IR camera. Thermosonics can be applied equally well to quite large and irregularly shaped objects, and to small delicate objects using the same apparatus. It has demonstrated the capability of detecting defects in materials ranging from brittle ceramics, to soft metals and composites. Progress on the development of this technique will be presented. Also, studies on some fundamental issues such as dependence on frequency of an excitation source will also be discussed.

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Finite-Element Analysis Assisted by Stress Measurement Using Infrared Thermography

E. Umezaki and T. Suzuki

A method was developed for obtaining stresses in structures using finite-element analysis assisted by infrared stress measurement. This method is divided into three steps. The first step involves the measurement of isopachics on a part of the surface of the model of an analyzed product by infrared stress measurements. The second step involves the confirmation of the model shape and boundary condition necessary for FEA by comparing isopachics obtained by infrared stress measurements with simulated isopachics obtained by FEA with a model shape under every conceivable boundary condition. This second step is repeated until the isopachics agree. The third step involves the calculation of stresses by FEA with the model shape and the boundary condition confirmed by infrared stress measurements.
The method was applied to T-shaped structures subjected to bending loads. The results showed that the method was effective for obtaining stresses in structures.

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DOPANT PROFILING IN SILICON WAFERS BY FOURIER TRANSFORM INFRARED SPECTROSCOPY

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A novel non-destructive method for one-dimensional dopant profiling in silicon wafers is presented. The approach is based on the measurements of the infrared reflectivity of the sample, performed by a Fourier Transform Infrared Spectrometer, so it can be used both for *ex situ* and *in situ* analysis. In this work, we introduce a formulation of the problem that permits to linearly relate the field intensity reflected by the wafer to the doping profile. In particular, starting from the integral relations of the optical tomography that permit to relate the reflected field intensity to the dielectric profile of the sample, we consider the first order approximation of the reflected field intensity about a reference profile. By means of the relationship (Drude-Lorentz model), which holds true at infrared wavelengths, between the free carriers concentration and the complex permittivity of the semiconductor material, we directly relate the infrared spectroscopy data to the dopant profile. From this formulation an iterative algorithm is developed, such as at each iteration step the problem is formulated as the minimization of a proper functional representing the error between the measured reflected intensity, at different wavelengths, and the model data. In the first step we can assume as reference profile either the homogeneous one or the expected profile, the recovered profile is then used as reference profile in the next step and so on until a negligible variation between two successive recovered profiles is achieved. The main advantage of this approach is that the unknown carriers concentration profile is not described by a "parametric" expression of a known function as in, but an expansion in a finite series of basis function is used. In this way we do not need to fix a priori the functional form of the doping profile.
Numerical simulations and the first experimental results will be presented to show the effectiveness of the proposed approach.

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Thermal non-destructive testing in temporal and frequency domain

Sougrati BELATTAR, Abdeltif OBBADI, Amal TMIRI, Smail SAHNOUN

The thermal non destructive testing is a method of inspection and analysis of the various structures homogeneity by the acquisition of information at the possible system accesses, and the establishment of a relation between this information and the imperfections that they contain. The presence of a defect in a given structure, generally, changes thermal flow value compared to a structure devoid of any defect. This is due to the thermophysical characteristics difference between the structure and the defect. If this difference is large, the variation of the surface temperature profile will be significant and can be detected. In this article, we present two approaches for the analysis of the thermal transfer in the plane walls containing plane defects. The first one ,in the frequency domain, is based on the transfer function concept , the second one, uses the numerical control volumes method. With simulations, describing several practical configurations, and in the assumption of one dimensional conduction, the temperature response and the thermal transfer function evolutions are analysed.

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Thermography Shows Damaged Tissue and Cavities Present in Trees

Dr. Alessandra Catena

The detection of hidden cavities and/or rotten tissue in trees has now become of major interest for plant pathologists, Curators of historic gardens and even for Municipalities, because a damaged tree poses a threat to public safety, in that the damage can progress and cause the tree or parts of it to suddenly crack down.

The various diagnostic systems currently used are generally time-consuming and require the presence of personnel, because they require the use of ropes (tree-climbing), ladders or scaffolding in order to examine the parts of a tree that cannot be reached from the ground, or can be dangerous for man. Such systems are often invasive, in that they envisage that holes be carried out onto the plant. The holes made onto the tree can become the access and spread routes for pathogens. Some of these methods can be dangerous for man, in that they use radioisotopes or X-rays sources.

Monitoring the progress of the pathology over the years can prove complex with these systems.

The use of a hand-held infrared (IR) camera allows to spot the presence and size of possible cavities/damage, also in the aerial parts of imposing trees, from the ground and in real time. The method proposed is non invasive and totally harmless to man. This is a quick, safe and user-friendly system of investigation and, among other things, since it doesn't rely on holes made into trees, it doesn't allow existing pathogens or fungi to spread, confirming the effectiveness of non-destructive methods also in this new sector. This is also the only system among the known investigation apparatuses that provides for images of the conditions of the plant.

The possibility to check the progress of the phenomenon with certainty over the years through the simple comparison of the relative images is another element in favour of this method, some examples of which are shown hereafter.

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ANALYSIS OF CRACK DISTRIBUTION AND PROPAGATION IN CONCRETE USING X-RAY COMPUTED TOMOGRAPHY

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Industrial X-ray computed tomography has been applied to make time-resolved measurement of the initiation and growth of cracks within concrete specimens in order to characterize damage associated with delayed ettringite formation (DEF)[1]. Laboratory specimens of concrete were cast with variations in one of two possible variables of interest: potassium level or type of fine aggregate. The specimens were stored in water for times of up to one year, during which they were periodically removed from the bath to be measured for expansion and also scanned by X-ray tomography. The X-ray computed tomography system consists of dual-focus 420-kV continuous x-ray sources and a digital detector. The detector consists of 512-channel linear array $CdWO_4$ detector elements. The nominal spatial resolution of the image is 0.250 mm

Image processing and analysis software, ImageTool (2), running on a windows NT4.0 platform was used to process the CT images and to determine the crack distribution. The processing steps included length scale calibration, thresholding, object recognition, and automated area calculation. The distribution of cracks correlates with the amount of potassium present. Significant cracks were observed in specimens cast with silicate-type fine aggregates, but were not observed in specimens cast with carbonate-type fine aggregates. Furthermore, the crack areas increased with time for the concrete cylinders, but the crack growth did not show a simple correlation with expansion data.

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Development of a phased array transmitting equipment for ultrasonic testing of concrete

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Phased arrays are widely used for ultrasonic testing in medical applications or metals. Using frequencies between 0,5 MHz and 10 MHz, this technique is able to displace, to steer and/or to focus the ultrasonic beam in the specimen, if each single piezoelectric transducer of the array will be excited time controlled.

The typical frequency range for ultrasonic testing of concrete is between 50 kHz and 200 kHz. In this frequency range the necessary time delay for steering the ultrasonic beam can be obtained by using commercial obtainable components. As a result, the hardware development was concentrated on the transmitting power stages and the interface.

The phased array transmitting equipment consists of a computer with timer boards and an external frame with 10 transmitters for the ultrasonic probes. As a compromise between circuit complexity and best possible excitation, square pulses with adjustable pulse width are used. In this way the excitation of different ultrasonic probes can be optimized.

Measurements were done at specimens with different maximimum aggregate size. The focusing and steering of the ultrasonic beam was measured using a laser vibrometer in transmission technique. Measurement results were compared with a numerical model.

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INELASTIC NEUTRON SCATTERING MEASUREMENT OF POZZOLAN PERFORMANCE IN PORTLAND CEMENT

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Pozzolanic materials such as silica fume or fly ash are added to Portland cement concrete mixes to reduce shrinkage and increase durability. One measure of a pozzolan's performance is its consumption of calcium hydroxide, which is a product of the main cement hydration reaction[1]. Inelastic neutron scattering has been applied to make *in situ* measurement of the amount of calcium hydroxide in cement paste samples as a function of pozzolan mix fraction, composition and particle size distribution. This is a molecular vibrational spectroscopy technique that identifies calcium hydroxide by the major phonon mode of the OH group oscillations at 41 meV [2]. The method detects calcium hydroxide in both crystalline and amorphous forms. The measurements were made at the recently completed Filter Analyzer Neutron Spectrometer (FANS) at the Center for Neutron Research at the National Institute of Standards and Technology in Gaithersburg, MD, which has a resolution on the order of 1 meV. The nondestructive nature of the technique makes it possible to remeasure the same specimen over time and thus to determine the kinetics of the pozzolanic reaction.

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AUTORADIOGRAPHIC MEASUREMENT OF POTASSIUM DISTRIBUTION IN PORTLAND CEMENT CONCRETE

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Potassium has been identified as a significant agent of concrete deterioration. A nondestructive method to measure it has been developed based on autoradiography of its naturally radioactive isotope ^{40}K, which yields both a beta particle and a gamma ray photon. The technique uses the storage photostimulable phosphor imager (SPP) system, that can have a spatial resolution as fine as 50 μm, and a dynamic range $>10^5$ [1]. For field application, a rugged cassette holder has been fabricated which firmly attaches the plate to the concrete structure during exposure while at the same time shielding it from background radiation. The resulting digital image is then processed to yield the bulk average potassium content. Further image processing reveals the spatial distribution of potassium, which can be correlated with visible light images of cracks and other damage features of the concrete.

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THE QUALITY ASSURANCE HANDBOOK AS A USEFULL INSTRUMENT FOR THE PRACTICE

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The handbook lays down the procedure for planning, production and testing and thereby for quality assurance. The personal competence for every step in planning, production and checking the quality is unambiguously as well.
Due to current checks for the state of the art, the practitioner can be sure to act according to the latest norms and rules. Quality examination beeing indepedent of production and in the sole responsibility of the management quality assurance is guaranteed to be continuous and transparent. Thus every collaborator exactly knows his responsibility and confirms by his signature the execution according the regulations. As the customer too has accepted the handbook, he also accepts a certain kind and amount of deviations. So controverses are avoided between him and planning, production and quality assurance by the methods and extends of examination and the tolerable deviations layed down in the book. The moment of examination is incestable as well. Finally, soms aspects of the application of nondestructive methods in situ are presented; in this field the 45 years experiance warrants for quality !
The field of testings includes concrete, wood, masonry, metall, metall - alloy, cast metall and weldings, considering the last technical stand.

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New Development in Acoustic Imaging Inspection, Ultrasonic Materials Evaluation for Vehicle Quality Control

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The role of nondestructive materials characterization and evaluation (NDE) is changing and will continue to change dramatically. This paper deals with the analysis of the novel acoustic imaging NDE methods and technique for inspection the internal structure of the various materials and products in automotive industry, including different metals, alloys, composites, ceramics, multilayer structured materials, polymer blends, various joints, etc.

The Imaging C- and B- scanning techniques using high-frequency ultrasonic beams have become increasingly important as a means of NDE and QC in mass production, especially for on-line control in automotive, tool and electronic industries, including NDE of Al-castings, spot welds, composite and polymer materials, etc. All of these products require examination of even the smallest defects or voids in the materials. To realize effective QC in products and materials using ultrasonic-imaging techniques in mass- production lines, new generation of high-speed and high-resolution portable acoustic imaging systems are required to be developed for various industrial needs. Real-time process monitoring for more effective and efficient real-time control of various processes and as a result improved vehicle manufacturing quality control inspection and reliability will now become a practical reality. It has become increasingly evident that it is both practical and cost effective to expand the role of new NDE and quality control technique to include all aspects of vehicle's production and to introduce it as much as earlier in the manufacturing cycle.

Works in the ultrasonic vision systems has given rise to a new experimental means for generating images of the interior of matter with many practical applications. Such technique has the potential to provide a reliable, rapid and cost effective methods to visualize high contrast small scale failures and defects at different depths within inspected parts. Provided this technology can adapted to high volume manufacture, it has considerable promise for application to the advance manufacturing quality control inspection.

The new materials structures, joints, parts, components made from various materials demand the innovative applications of modern NDE techniques to monitor and control as many stages of the vehicle production process as possible. Simply put, intelligent advance manufacturing is impossible without integrating modern nondestructive evaluation into the production system.

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Evaluation of the cure behaviour of epoxy resin using rheometric and ultrasonic techniques

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Advances in the development of resin injection moulding techniques has meant large scale commercial production of high-quality composites is a realistic option. New resin systems in combination with techniques such as Resin Transfer Moulding enable relatively short process time (e.g. 30 minutes) for large parts. To facilitate such short cycle times manufacturers operate within a small processing window leaving little room for error.

A typical RTM process involves the impregnation of a fibre structure. After impregnation the resin forms a gel (rubberlike material) and then vitrifies to the glassy state. These transformations are accompanied by significant changes in the viscoelastic properties of the resin system which are related to the formation of a crosslinked molecular structure. In this work the physical changes in the resin system are detected using a parellel plate rheometer for Dynamic Mechanical Analysis. Analysis of resin cure using rheometry or other laboratory techniques provides the basis for charaterisation of epoxy resins. However one or a combination of several factors, including permeability of fibre, geometry of part, pressure, part thickness, variations in temperature etc. mean that a complimentary process monitoring technique should be employed to monitor resin cure in the mould. Dynamic mechanical material characterisation in the mould itself is possible using an ultrasonic through transmission technique. The intention is to apply this technique to monitor and document the curing process for composite parts, thereby providing a large improvement on present process and quality control techniques.

In this presentation a detailed characterisation of the epoxy resin will be employed in order to aid the interpretation of the ultrasonic sound velocity and attenuation results. This information is crucial to the industrial implementation of this technique.

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Rubber processing monitored by ultrasound

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During manufacturing process both form filling and vulcanisation reaction must be optimised. Up till now no method is used in practice giving the possibility to get process information direct from the mould.
In the BAM during the last years an ultrasonic measuring system including sensors for high temperatures and pressures was developed for online monitoring of thermoset processing. By improvements in the measuring accuracy of sound velocity we were successful now to watch the changes during rubber vulcanisation also.
We made overview experiments using natural rubber with wide variation of sulphur content from 1.5 phr to 40 phr, it means between soft and hard rubber adjustment. We found, that depending on sulphur concentration the change of sound velocity during vulcanisation is representative. The degree of change in sound velocity correlates with the sulphur concentration. Also for values less than 5 phr (soft rubber) an increase is clearly seen but some improvements in resolution are worthwhile.
All ultrasound measurements are compared with curemeter (Vulkameter) curves. In analogy to the standard procedure the order of reaction and activation energy were determined by using different vulcanisation temperatures in both curemeter and ultrasound experiments. The activation energy determined from both methods was very similar.
Finally we are optimistic that the ultrasound method can be brought into an application like an online curemeter in the rubber mould.

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programme no. **B11-3**

Methods of Analysis of Dielectric Cure Monitoring Data for Process Optimisation

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In-situ, non-destructive dielectric technique can be used to monitor the nature of the structural changes which occur in the process of cure, in which an initially liquid blend of resin monomer and hardener turns to a solid, 3D-networked (gelled), glass. The ultimate aim of real-time, in situ, cure monitoring in the manufacture of thermoset composites is to get away from the traditional off-line, destructive mechanical testing of the finished parts, to give the ability to monitor every part during formation, and to "tune" the process so as to reduce variability and scrap rate. Among the candidate monitoring methods, the dielectric techniques are undoubtedly the most developed and best validated. The group at Cranfield University has been active in the field of dielectric monitoring of thermoset cure for over a decade [1]. The development of the technology is such that the technique of dielectric cure monitoring is under active consideration, for R&D and for manufacturing, by a number of UK-based aerospace composites manufacturers.

In the continued process of adaptation of the monitoring technology to industry needs, a number of considerations have arisen, regarding the most appropriate treatment of the dielectric data [2,3]. The present paper will expose the most recent developments in the use of complex impedance analysis to identify the temperature-cure time regions associated with the processes of gelation and vitrification in epoxy based resins. Data from two representative, commercial, 'aerospace composite' resins will be used, namely the RTM6 and F913, illustrating the differences and similarities in the dielectric response during cure. The technique of equivalent circuit analysis will be used to model the changing dielectric signal in terms of sets of electrical elements, which represent different facets of the curing phenomenon. This concept, coupled with the use of genetic algorithms for effective numerical modelling, shows promise in terms of providing information suitable for optimisation and control of the complex cure processes.

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Integrated Endoscopy - Bridging the Gap between Diagnosis and Action

Dr. Wolfgang Ohnesorge

Industrial Endoscopy has been introduced in the early twenties of the last century. Refinements in both optics and electronics have considerably extended the visualization limits for otherwise unaccessible objects. Combination of endoscopes with other NDT methods has either lead to further improved flaw imaging (e.g. by fluorescent penetrants) or serves to extend the access range of these methods (e.g. Eddy current testing).

Transgressing the border of pure NDT, endoscopy offers not only the diagnostic tool but also the remedy: The latest developments combine endoscopic and material processing tools into integrated instruments which allow for detecting and curing material defects within one process.

Two examples from turbine technology show the tremendous progress and cost saving effect of the integrated approach:

1. The in-situ repair of damaged aeroengine compressor blades (so-called "blending on-wing") cutting ground times from days down to a few hours
2. The finishing of precision casted hollow turbine blades for stationary gas turbines. Small casting defects which suppress the internal air cooling are removed saving the expensive blades from being scrapped.

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On-line methods for the determination of mechanical properties - state of the art and critical assessment of measurement uncertainty

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During the production of thin sheet material especially used in the automotive industry the assurance and control of quality relevant properties like geometry, surface coating or mechanical properties is a strong competition argument. In order to procure and demonstrate the homogeneous properties of steel strips a complete monitoring and controlling of technological properties and process parameters (e.g. temperatures, degree of rolling or geometries) on one hand and destructive random sample tests on the other hand is state of the art today. Nevertheless it becomes more and more important in the steel industry to characterize the material properties during the production process e.g. in cold rolling mills, inspection lines or coating lines with integrated annealing furnaces. In the case of steel qualities for car bodys the determination of yield strength is of major significance. Beside a 100 % inspection process-integrated testing offers the opportunity for an extended control and a better understanding of the production process itself, e.g. optimum range of strip travel speed and furnace temperature. Non-destructive methods on electromagnetic basis offer a way to solve this problem. Different concepts like incremental permeability, remanent field analysis or analysis of upper harmonics have therefore been developed and tested at different steelmakers during the production of steel strips. In principle all these methods are based on the analogous interdepedencies between the magnetic and mechanical properties on one hand and the structural material parameters on the other hand. It is characteristic for all measuring and calibration strategies that basically a comparison between results of destructive measurements like tensile test and the different magnetic parameters will be performed to calculate approximation functions. This can be done using statistical analysis, e.g. multiple regression methods. The aim of this paper is to give an overview of the state of the art of nd on-line methods available today and to make a critical assessment of measuring uncertainties of the calculated quantities, especially in respect to the determination of the yield strength. This takes into account a realistic estimation of error budgets both resulting of tensile test according to DIN EN 10002, Pt. 1-6, and the precision of measurement of the magnetic quantities in an industrial environement.

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programme no. **B11-6**

Acoustic Studies of Composite-Material Interfaces

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We review several recent acoustic studies of interfaces in composites. Measured physical properties are either elastic constants (sound velocities) or internal frictions. Considered materials include (1) glass-fiber/epoxy, (2) graphite-fiber/aluminum, (3) silicon-carbide-fiber/titanium, (4) diamond-particle/copper, (5) alumina-platelet/mullite, (6) graphite-epoxy/aluminum laminate. We emphasize the importance of combining measurements with solid-mechanics modeling.

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Micro cracking and stress state under fatigue loading of CFRP

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Advanced structures have to endure high, dynamic loads. Applicating higher load levels in progressive CFRP (Carbon Fibre Reinforced Plastics) structures requests the knowledge of the fatigue behaviour, as this becomes of central importance for design. With respect to the specific properties of CFRP the measurement and correlation of micro cracking with the stress state is the key for the description of damage accumulation and fatigue behaviour.

Several fatigue tests on CFRP laminates were performed to create defined damage states. The characterization of defects were made by the NDT methods ultrasonic and X-ray refractography. Analytical and numerical (finite element analysis) calculations were done to analyse the stress state with respect to the loading conditions and to predict the effects of micro cracking.

With regard to real loading conditions of CFRP, studies on tube samples were investigated to determine the influence of „free edge effects" and to perform two dimensional (tension-torsion) tests. Measurements with X-ray refractography of inner surfaces on CFRP samples in the damaged state show a good correlation with the prediction of analytical and numerical calculations. The results show that tube samples enable a better understanding of the intralaminar fatigue behaviour of CFRP.

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Characterisation of damage accumulation during fatigue in fibre reinforced thermoplast by X-ray refraction

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Because of their good specific properties polymer composites are applied for high performance components. The non destructive characterisation of composite materials requires specific methods to master the demands of modern technologies. Micro damage structures after fatigue of short glass fibre reinforced injection moulded tensile test samples of polybutyleneterephthalate (PBT-GF) are investigated by X-ray refraction.

The test samples are treated by dynamic loading (fatigue) at 50 % and 80 % maximum stress and up to 180 000 cycles. Furthermore the residual strength is determined after 30 %, 60 % and 90 % of the lifetime. The resulting damage patterns are imaged by X-ray refraction topography at different stages of treatment. The relatively new X-ray technique combines the scattering sensitivity of ultra small angle X-ray scattering (USAXS) for micrometer scale surface structures by refraction effects and spatial resolution by scanning the sample. Due to the preferred fibre direction along the sample axes, the debonded fibre surfaces scatter selectively perpendicular and the transverse micro cracks scatter parallel to the axes. This provides the capability of separate detection of both damage phenomena.

The spatially averaged inner surfaces by cracks and fibre debonding increase continuously in correlation to the number of load cycles (damage accumulation). Approximately half of the crack surfaces are created at 30 % of the lifetime. Cycling at 80 % maximum stress creates a three times higher crack surface than at 50 % maximum stress at all fatigue levels. The amount of debonded fibres does not differ significantly. The residual strength after 30%, 60% and 90 % of the lifetime performs a linear decay over crack surface. However the decrease at lower loading is six times faster. This proves the dependence of the residual lifetime and strength on the crack surface. Additionally the decrease of these properties depends strongly on the maximum loads during cycling: Higher loads create larger surfaces. Presumably many short cracks can be tolerated by the material much better than few large ones. All refraction topographs show rather even spatial distribution. This demonstrates the typical capability of the composite to distribute stress homogeneously.

The resulting correlations of microstructures and mechanical properties provide new input into modelling of damage mechanics and encourage further investigations into advanced materials by X-ray refraction.

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Ultrasonic Characterization of Fatigue Cracks in Composite Materials

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Microcracking in composite structures due to combined fatigue and cryogenic loading can cause leakage and failure of the structure and can be difficult to detect in-service. In aerospace systems, these leaks may lead to loss of pressure/propellant, increased risk of explosion and possible cryo-pumping. The success of nondestructive evaluation to detect intra-ply microcracking in unlined pressure vessels fabricated from composite materials is critical to the use of composite structures in future space systems.

The work presented herein characterizes measurements of intraply fatigue cracking through the thickness of laminated composite material by means of correlation with ultrasonic resonance. Resonant ultrasound spectroscopy provides measurements which are sensitive to both the microscopic and macroscopic properties of the test article. Elastic moduli, acoustic attenuation, and geometry can all be probed. The approach is based on the premise of half-wavelength resonance. The method injects a broadband ultrasonic wave into the test structure using a swept frequency technique. This method provides dramatically increased energy input into the test article, as compared to conventional pulsed ultrasonics. This relative energy increase improves the ability to measure finer details in the materials characterization, such as micro-cracking and porosity. As the micro-crack density increases, more interactions occur with the higher frequency (small wavelength) components of the signal train causing the spectrum to shift toward lower frequencies.

Several methods are under investigation to correlate the degree of microcracking from resonance ultrasound measurements on composite test articles including self organizing neural networks, chemometric techniques used in optical spectroscopy and other clustering algorithms.

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Interface Damage Growth Monitoring in Polypropylene Thermoplastic Composites

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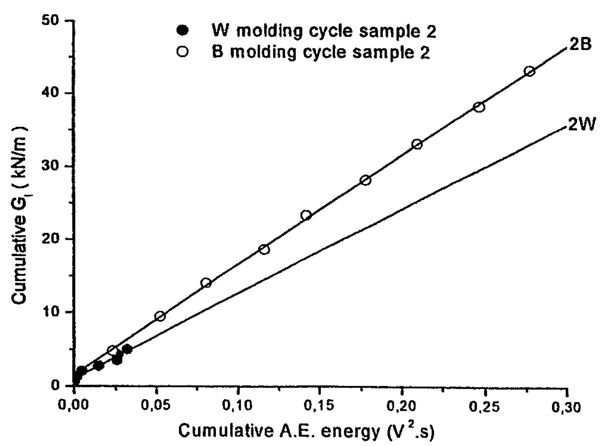
Thermoplastic composite materials are often considered for many industrial applications. However, one major limitation in its use relies in its vulnerability towards damage propagation that can be initiated by various factors such as an impact load on the structure, shear stresses, compressive loads, as well as the manufacturing process defects. In composite structures, the most critical time would be at the onset of crack development. Acoustic Emission techniques can allow following micro-events in a real time. Sudden internal stresses due to stress redistribution caused by crack growth liberate mechanical stress waves that travel through the material and eventually are detected by a sensor. The purpose of this paper is to show how the use of Acoustic Emission techniques, can help monitor failure activities such delamination and interface damage in thermoplastic composite materials, by correlating acoustic emission signal parameters and fracture toughness expressed by strain energy release rate dissipated in Double Cantilever Beam (DCB) in opening mode (mode I). Using the linear elastic fracture model (LEFM), the strain energy release rate was correlated to Acoustic Emission energy dissipated in the material. In order to understand the behaviour of thermoplastic composites with interface damage and delamination, a mode I interlaminar fracture toughness are numerically evaluated. The virtual crack closure methods are employed in the finite element analysis to calculate the strain energy release rates for polypropylene composites. The results, in figure, show that acoustic emission is a valid technique that can be used to monitor interlaminar damage propagation in polypropylene composite material and to evaluate the quality of interfacial behaviour of the composite depending on the moulding conditions.



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Characterization of the Fatigue Damage of Advanced Ceramic Composites by Scanning Acoustic Microscopy

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In this report we will demonstrate the use of the acoustic microscope for non-destructive characterization of the damage in fiber composite due to fatigue. Four fiber composite (continuous ceramic fiber composites) samples subjected to fatigue damage were studied by acoustic microscopy. The damaged samples were inspected by the high frequency Leitz Elsam microscope and the low frequency time-resolved acoustic microscope developed at the Institute of Biochemical Physics (IBCP), Moscow. It was demonstrated that high frequency microscope provided very powerful method of detecting subsurface cracks in composite matrix. In the paper published previously, the low frequency acoustic microscope was chosen to study the internal fatigue damage in samples without any preparation for SAM investigation [1]. The surface of the fiber sample was rough due to high thickness of the fiber bundles breaking the surface. It was shown that internal (several milimeter in length) cracks propoagate parallel to the sample surface and could be detected by the time-resolved acoustic microscope [1]. In this report we show that a small subsurface crack of several millimeters in length becomes visible after polishing the sample surface. Most of the observed cracks run perpendicularly to the bundles of fibers. Samples with different fatigue loading were investigated and subsurface cracks distributions have been discussing.

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Non-destructive testing of thermal barrier coatings by impedance spectroscopy

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Thermal barrier coatings (TBCs) are mandatory in today's stationary and aircraft gas turbines. They are used for the combustion chambers and guide blades. Degradation during operation is resulting in a delamination of the coating and a failure of the device.
In this work, a non-destructive method is developed to examine thermal barrier coatings (TBC) by means of electrical impedance spectroscopy. The main goal is the development of a model for TBC systems which correlates the measured impedance with structural parameters and different types of defects. This method can be used in quality control as well as in routine maintenance to evaluate the degree of damage and to predict the remaining lifetime of the device.
To gather knowledge about the electrical properties of the coating itself, free standing TBC were produced. Samples were prepared by plasma spraying yttria doped partial stabilized zirconia layers (YSZ) onto steel substrates. Different layers varying in porosity and thickness were manufactured. The layers were removed from the substrate and annealed at 1250 °C for up to 1000h in air. The microstructural changes due to annealing were analyzed by SEM, the mechanical properties of the coatings were evaluated by 4-point-bending tests and the phase composition was examined by XRD measurements. After annealing, the coatings were contacted by sputtered platinum electrodes and characterized by electrical impedance spectroscopy in a temperature range from 200°C to 500°C. The impedance of the coatings changed significantly with the annealing time. Below 100h annealing time a continuous drop in the resistivity was observed. This correlates with the densification of the coating due to thermal treatment. Between 100h and 1000h a raise in resistivity appears together with a change in the relaxation frequency, which could be correlated to a partial phase transformation from tetragonal to monoclinic. The volume increase related to the phase transformation results in a microcracking of the coating. The correlation between impedance measurements and microstructural properties will be presented.

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In-Situ Characterization of Dry Surface Contact Using Ultrasound

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This paper presents ultrasound as a technique for in-situ characterization of dry surfaces in contact. The key of the method is to accurately determine the degree of acoustic coupling between two bodies forced together. Quantitative values of surface stiffness are determined while a qualitative evaluation of real contact area is obtained. This novel method is described and applicability demonstrated through results obtained from surfaces of aluminum and from C/C composites in contact. Conventional ultrasonic equipment was used to measure the acoustic transmission or reflection coefficient. Calculations of contact stiffness were then made by implementing an interface model consisting of a set of distributed springs. This energy conserving model revealed that average contact stiffness is nearly proportional to the square root of the nominal contact pressure when low loads are applied. Hysterisis from load-unload cycles demonstrates the interface is not energy conserving, and additional elements for the interface model are required. The mechanisms for loss from the interface is considered to be interface damping from plastic deformation and micro-slipping of surface asperities.

Investigations of surfaces with different preparations were performed. Assessment of real area of contact found that a smoother surface (lower R_a) achieves a higher degree of true contact area than a rougher surface. Higher average contact stiffness, and fastest rate of increase, was found for surfaces with low R_a. This evaluation approach is useful in that characteristics can be determined while surfaces are in contact on materials that are optically opaque. Since it relies on elastic strain energy transfer across the interface it is a direct measure of surface mechanical properties.

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Contactless characterization of coatings with a microwave radar sensor

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Free field microwave methods are well suited to characterize dielectric materials both in nondestructive and in contactless way. However, variations of the distance between test object and microwave sensor (air gap) are influencing the measuring values as the air gap is part of the system under test. By additional and independent air gap measurement it is possible to get measuring values which are necessary to correct the microwave measuring values with regard to air gap variations. These measurements can be performed with laser triangulation method or with air coupled ultrasound with an accuracy of about 10 µm.

One potential application is the online surveillance of the coating process of steel pipes. Coat is made of plastics and has a thickness of some mm. This paper describes some investigations that have been performed using a FMCW (Frequency Modulated Continuous Wave) radar with carrier frequency of about 94 GHz in reflexion mode and in combination with air gap mearurement. The accuracy of thickness measurement is better than 0.1 mm which is sufficient for that purpose. Tests with increased coat temperature to simulate the coating process at extrusion location have yielded no measurable influence of temperature on microwave measuring quantities in comparison with room temperature tests.

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Photoacoustic nondestructive quality control of microwelded connection of semiconductor devices and integrated circuits

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The results of a photoacoustic quality control of microwelded connections of semiconductor devices are presented. The photoacoustic images of various quality connections executed by ultrasonic welding were obtained and analysed. A technique of the connection quality evaluation on the photoacoustic image contrast was proposed.

The technique of adhesion quality control by photoacoustic microscopy is based on the assumption, that the off-standard connections are characterized by the delamination of connected surfaces. In this case the amplitude and the phase of the photoacoustic signal in the place of delamination are different from the amplitude and the phase in the place of connection. Therefore, the quality of adhesion can be determined on the contrast of the photoacoustic image.

The results of researching have shown a possibility of the photoacoustic registration and visualization of delaminations of upper layers on frequency up to 10 kHz, for which the upper layer is thermally thin. The computer analysis of photoacoustic image of connections allows evaluate their quality and reject semiconductor goods on principle "valid" - "not valid". The results of the photoacoustic investigation of microwelded connections is well identified with a destructive method of quality control on breaking load and character of failure.

The results of photoacoustic measurements prove that the photoacoustic microscopy can be successfully applied for nondestructive quality control of microwelded connections of semiconductor devices and integrated circuits.

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